

~~5373~~
~~232~~
~~Copy 1~~

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

8 DEC 1947
TECHNICAL MEMORANDUM

No. 1178

INVESTIGATION OF THE OPERATING PROPERTIES
OF THE LEAKAGE CURRENT ANEMOMETER

By Wilhelm Fucks

TRANSLATION

"Untersuchung der Betriebseigenschaften des Vorstromanemometers"
Deutsche Luftfahrtforschung, Untersuchungen und Mitteilungen Nr. 1203



Washington
October 1947

NACA LIBRARY
LANGLEY MEMORIAL AERONAUTICAL
LABORATORY
Langley Field, Va.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL MEMORANDUM NO. 1178

INVESTIGATION OF THE OPERATING PROPERTIES
OF THE LEAKAGE CURRENT ANEMOMETER*

By Wilhelm Fucks

Abstract: Freedom from inertia, erosion of electrodes, and reaction make the leakage current particularly appropriate for the measurement of flow velocities in gases. Apparatus previously described has now been improved by reducing the size of the electrodes by one one-thousandth, as is necessary aerodynamically, and by increasing the magnitude of the current from 1000 to 10,000 times; the latter result was obtained by use of mercury high-pressure lamps set up at the one focal point of an ellipsoidal reflector with the cathods arranged at the other focal point or by use of suitable X-ray radiation. Families of calibration curves were taken with a number of vivid tests conditions of the greatest variety and the operating properties of the instrument were widely elucidated by calculation of the sensitivity to fluctuation; this was done at first for operation at stationary conditions only; due to the freedom from inertia the instationary conditions were thus also given. Accordingly, the leakage current anemometer ought to be appropriate for investigations of turbulence.

- Outline:**
1. Statement of the problem
 2. Increase of the leakage current by use of strong means of radiation and reflection optics
 3. Effect of Induction. The problem of grounding. Transition to the glow discharge
 4. Families of calibration curves with UV-radiation
 5. About the theoretical and experimental determination of the sensitivity to flow fluctuations of the leakage current anemometer.

*"Untersuchung der Betriebseigenschaften des Vorstromanemometers." Zentrale für wissenschaftliches Berichtswesen der Luftfahrtforschung des Generalluftzeugmeisters (ZWB) - Berlin-Adlershof, Untersuchungen und Mitteilungen Nr. 1203. Aachen, February 4, 1944.

6. Tests with various materials for electrodes
7. Experiments in a strongly inhomogeneous field
8. Preionization by means of X-rays
9. Summary

1. STATEMENT OF THE PROBLEM

The first treatise on the leakage current anemometer (reference 1) started from the fact that it was unknown at first whether by leakage currents fields of calibration curves are at all obtainable and whether in the affirmative case they can be utilized anemometrically. This problem was cleared up completely. Fields of calibration curves were taken by various kinds of preionizations, (ultra-violet radiation, radio-active radiation). The measuring apparatus were at first arranged for stationary flow phenomena exclusively. The absolute amounts of amperages of the dark currents had the order of magnitude $10^{10} \dots 10^{-10}$ amperes.

In the same treatise a theory of the calibration curves was developed.

The present treatise starts from the statement that the amperages of the fields of calibration curves measured so far which were fully sufficient for the measurements of stationary air flows were about 10,000 times too small for the measurement of finer fluctuations. Moreover, the size of the electrodes used so far was from an aerodynamic point of view more than 1000 times too large.

In order to obtain larger currents, first of all experiments with newly developed ultra-violet lamps were carried out. For further amplification of the current, experiments were made with a quartz optic, then with a metal reflector. With the aid of the latter arrangement the desired increase of the current to 10,000 times its magnitude could be obtained even with a smaller modern ultra-violet lamp although the size of the cathode compared to the earlier experiments had to be reduced to about one-thousandth.

Also, experiments with preionization by X-rays could be carried so far that finally an increase of the current to 10,000 times the amperage of the earlier experiments was obtained.

Meanwhile a strong radio-active preparation became available, which is being tested at the time; a brief report about these tests will be made.

After the desired increase of the current to a satisfactory value was obtained, families of calibration curves were taken with electrodes of aerodynamically usable form under the various operating conditions of interest and were evaluated.

Following, a more detailed report is given about the enumerated treatises.

2. INCREASE OF THE LEAKAGE CURRENT BY USE OF STRONG MEANS OF RADIATION AND REFLECTION OPTICS

In the first treatise about the leakage current anemometer (reference 1), where UV-radiation was used for preionization one did not succeed in taking fields of calibration curves for a homogeneous field with wind velocities up to 125 meters per second. With means available at the beginning the taking of families of calibration curves proved to be possible only with a strongly inhomogeneous arrangement of electrodes.

Quantitatively there resulted for a homogeneous field and very large sizes of electrodes a spurious current of the order of magnitude of 10^{-11} amperes (reference 1, fig. 29). For the inhomogeneous field there resulted from a cathode plate of 30 millimeters ϕ opposite a point as anode a spurious current of about 10^{-10} amperes. The leakage current values where anemometric measurement could be applied are two to five times higher.

The calibration curves of the first treatise measured with preionization by α -rays show amperages of the same order of magnitude (figs. 1, 39, and 41).

In this chapter the further development with UV-radiation will be described. The arrangements treated in chapter 1 still had two essential disadvantages for practical purposes: the sizes of the electrodes were about 1,000 times too large and the densities of the currents about 10,000 times too small.

The problem to be solved consisted therefore of reducing the electrodes to very small cross sections of the order of magnitude of 1 millimeter² and obtaining, as far as possible, in spite of this reduction higher amperages than had been measured so far. With the

former radiation one obtained for an electrode of 30 millimeters ϕ spurious currents of about 5×10^{-10} amperes. The production of spurious electrons can be assumed as distributed - to some extent - evenly over the cross section. If one reduces the cross section from 30 millimeters to 1 millimeter, there results a cross-sectional reduction at the ratio 706:0.8, that is, to about one-ninehundredth. With aid of the old means of radiation one obtains thus a spurious current amperage of about 5×10^{-13} amperes.

With this amperage there was no prospect of performing the measurement of fluctuations. If one assumes for it several thousandths to hundredths of the original current, one obtains fluctuations of the current of the order of magnitude of 10^{-15} to 10^{-16} amperes, the amplification of which encounters, for the available frequencies, unsurmountable difficulties.

The first goal was therefore to increase the spurious current density by at least four powers of ten by using new means of radiation. The firm Osram was kind enough to place modern high-pressure mercury vapor lamps at our disposal for the desired purpose.¹

The lamp was at first placed in a casing according to figure 1. With its aid a leakage current curve according to figure 2 was taken. The arrangement of the electrodes was here already reduced to aerodynamically useful dimensions: platinum electrodes of about 1 millimeter ϕ , distance of the electrodes 2 millimeters. Nevertheless the currents lie still between 10^{-8} and 10^{-7} amperes.

Figures 3 and 4 show the installation of a lamp 10 times as strong. With this lamp a leakage current curve according to figure 5 was obtained, with platinum electrodes of 1 millimeter ϕ and a distance of electrodes of 3 millimeters. Here the currents are already about 10^{-6} amperes in spite of the small sizes of the electrodes. However, the lamp is rather large and, due to the high DC amperage, the operation is dependent on the corresponding voltage source.

Thus one proceeded to a better utilization of the radiation of the lamps; first, an attempt was made to concentrate the radiation coming through a large solid angle through a quartz optic to the small cathode surface. The calculated lenses could not be procured within reasonable time; no good results were obtained with special but rather inappropriate lenses.

Therefore, a metal reflector was developed, the reflector surface of which takes the form of a nickel-plated copper cap of an ellipsoidal

¹I want to extend my thanks to the executive director of the Society for Study of Electric Illumination, Dr. Ewest, and also to Dr. Rompe, for their kind cooperation.

shape. The initial conception was as follows: if one places the UV-discharge at the one focal point of an ellipsoid, it will be possible to concentrate a large part of the radiation through the reflector at the other focal point of the ellipsoid. Nickel was selected because this material has for UV the strongest reflection coefficient. The photographs (figs. 6(a), 6(b), and 7) show the reflector with conical casing, lamp, and the arrangement of the electrodes.

The electrodes (small platinum wires with small arc welded spheres at the ends) are adjustable by micrometer screw. Both electrodes are fastened on tall amber supports (fig. 7).

Concerning the path of the rays it is to be noted that, first, the source of radiation is not a point source and that, second, the course of the rays is influenced by the quartz walls of the lamp. The focal point must therefore be ascertained by experiment.

Figure 8 is to show the effect of the reflector. With reflector there resulted for a distance of the electrodes of 2 millimeters the amperage presented at the left with voltage of 4.9 kv. With the reflector screwed off, no measurable current resulted even for 5 kv.

Thus with the new arrangements and expedients there resulted an increase of the current density by several powers of ten if the cathode of the anemometer was placed well into the outer focal plane. This is shown in figure 9 for the two distances of the electrodes 2 and 3 millimeters. For $L = 3$ millimeters, one measures already currents up to about 5×10^{-6} amperes. Therewith the desired amplification of the current to 10,000 times its previous value is obtained, although the cross section of the electrodes was reduced to one-thousandth of its former value; thus the entire arrangement was improved 10^6 to 10^7 times compared with the former arrangements.

Figure 10 shows the comparison of two calibration curves for radiation of different intensity, other circumstances being equal. Electrodes 1 millimeter ϕ Pt, distance 1 millimeter; curve A strong radiation, $U_z = 5100$ volts, curve B weak radiation, $U_z = 6580$ volts.²

Figures 11 and 12 are given as a supplement; they show in two different representations test results obtained elsewhere with another lamp, after reerection of the test arrangement.

²a = 26 millimeters and a = 56 millimeters are the lamp distances. The voltages are sometimes no unique measure for J_T .

3. EFFECT OF INDUCTION. THE PROBLEM OF GROUNDING.

TRANSITION TO THE GLOW DISCHARGE

A few operating peculiarities of the leakage-current anemometer with UV-radiation will be briefly discussed in this chapter.

Particularly in case of strong radiation, of larger distances with strongly inhomogeneous field conditions and of aptly selected resistance it happens that the leakage discharge changes almost imperceptibly into a "glow discharge" which keeps burning even after the radiation has been discontinued by covering the UV-lamp or disconnecting the lamp. The discharge then burns on the calibration curve of the so-called glow discharge, the properties of which are well known with amperages of about 10^{-5} amperes. If one, therefore, wants to work at higher amperages and larger distances of electrodes (order of magnitude 10^{-5} amperes and about 3 millimeters or more distance) and attaches importance to avoiding the glow discharge with its peculiarities one must make sure, by covering the lamp, that one really still deals with currents in the Townsend region. In this case the current reverts when the radiation is discontinued sharply to zero and one can ascertain, by employing a galvanometer sensitivity 100,000 to 1,000,000 times as high that the remaining current actually is only an isolated current error of permissible magnitude. One can also use the glow discharge anemometrically, as will be discussed in detail in another treatise.

In using the leakage current anemometer, particularly for larger ratios $\frac{L}{r}$ (L distance of the electrodes, r radius of the electrodes), one also has to take the inductive effect of objects nearby into consideration; in particular, the influence effect of the leads, the supports, and the protective casing at the reflector of the UV-lamp and, for instance, of the blower nozzles. The following experiment shows the influencing effect:

For a distance of electrodes of 3 millimeters, platinum electrodes of 1 millimeter ϕ the lamp with its protective casing is to be completely eliminated. The voltage is to be measured under these conditions. The voltage then is adjusted to a value about 5 percent below the ignition voltage. If the lamp which is at the potential of the earth is brought near the spark gap, ignition occurs at a distance of the lamp casing from the spark gap of about 6 centimeters, although the voltage lies 5 percent below the ignition voltage of the unaffected spark gap (Compare reference 2.).

The following observation is interesting and important for the operation as well as for judging the significance of the theory of the anemometer: namely, by reversing the polarity of the spark gap in the circuit of figure 13, under certain operating conditions the current will drop to a very small value. Thus, for instance even with the most intense radiation, with, for example, electrodes of platinum of 1 millimeter ϕ and a spacing of 3 millimeters, the current through the spark gap will be smaller by several powers of ten than that measured using the polarity shown in figure 13.

This fact is connected with the one side - grounding of the spark gap as can be recognized from the following consideration:

One first assumes both electrodes of the spark gap isolated and at the potentials u_{10} and u_{20} , respectively, with respect to ground. The potential difference of the spheres shall be designated by u_{12} . The corresponding partial capacities of the spheres with respect to the earth and one another shall be designated by c_{10} , c_{20} , and c_{12} . The charges of the spheres are denoted q_1 and q_2 . Then the following relations are valid:

$$\left. \begin{aligned} q_1 &= c_{10}u_{10} + c_{12}u_{12} \\ q_2 &= c_{21}u_{21} + c_{20}u_{20} \end{aligned} \right\} \quad (1)$$

Considering at first the symmetric potential distribution with opposite equal charges these equations are specialized as follows:

$$q_1 = -q_2; \quad c_{12} = c_{21}; \quad u_{12} = -u_{21} \quad (2)$$

$$\left. \begin{aligned} q_1 &= c_{10}u_{10} + c_{12}u_{12} \\ -q_1 &= -c_{12}u_{12} + c_{20}u_{20} \end{aligned} \right\} \quad (3)$$

$$\left. \begin{aligned} 0 &= c_{10}u_{10} + (c_{12} - c_{12}) u_{12} + c_{20}u_{20} \\ c_{10}u_{10} &= -c_{20}u_{20} \quad \text{or} \quad q_{10} = -q_{20} \end{aligned} \right\} \quad (4)$$

which is evidently clear at once.

If the second electrode is grounded, the equations (1) are specified as follows:

$$u_{20} = 0; \quad u_{10} = u_{12} = u \quad (5)$$

$$\left. \begin{aligned} q_1 &= (c_{10} + c_{12}) u \\ -q_2 &= c_{12} u \end{aligned} \right\} \quad (6)$$

thus

$$\left| \frac{q_1}{q_2} \right| = \frac{c_{10}}{c_{12}} + 1 \quad (7)$$

One now considers two limiting cases: first, the distance of the spheres L is assumed small compared to the sphere radius r :

$$\frac{L}{r} \ll 1 \quad (8)$$

Then

$$\frac{c_{10}}{c_{12}} \ll 1 \quad (9)$$

is valid, and therewith from (7) in first approximation

$$q_1 = |q_2| \quad (10)$$

as in the symmetrical problem.

Thus the maximum field strength in the center of the two spheres in (1) practically equals the corresponding field strength in (2) since here, in air, the fields are determined from

$$\oint E_1 df_1 = q_1 \quad \oint E_2 df_2 = q_2 \quad (11)$$

respectively; second, the distance of the spheres is assumed large in comparison to the sphere radius. Then one writes with

$$\frac{L}{r} \gg 1 \quad (12)$$

$$\frac{c_{10}}{c_{12}} \gg 1 \quad (13)$$

approximately:

$$\left| \frac{q_1}{q_2} \right| = \frac{c_{10}}{c_{12}} \quad (14)$$

That means, there is now $q_1 \gg q_2$ and therewith the maximum field strength on the isolated sphere also is large in comparison with the maximum field strength on the grounded sphere. (Compare reference 2.)

If a dark current flows between the electrodes, this circumstance gives rise to very different consequences, according to whether the grounded sphere is cathode or anode.

If the grounded sphere is cathode, a number of electrons is freed from it by the photo-electric preionization, and the electronic avalanche swelling in the direction from the cathode toward the anode, enters the strong field ahead of the anode. Thus a very strong ionization occurs and one obtains a high leakage current.

It is different when the grounded electrode is the anode. The photo-electrically freed electrons are then rapidly conveyed from the strong field - into a weak field - region at the anode and the electronic avalanche finds just at the places, where it reaches in the homogeneous field its very high values, no longer a strong accelerating field. Thus result the weak currents for this arrangement of poles.

This state of things must be taken into consideration for the comparison of the results of the earlier developed theory of the families of calibration curves (reference 1 p. 29 ff.) as well as for the theory of the sensitivity to fluctuation of the leakage current anemometer (reference 2). The theory is strictly valid only for homogeneous field, that is, for a circuit as shown in figure 13 the more accurately the greater the inequality

$$\frac{L}{r} \ll 1$$

is satisfied.

4. FAMILIES OF CALIBRATION CURVES WITH UV-RADIATION

In order to get to know the properties of the new arrangement (fig. 7) with very small electrodes and also considerably reduced distances of electrodes under various operating conditions, families of calibration curves were taken for the three mentioned distances of electrodes of 1, 2, and 3 millimeters, which are plotted in figures 14, 15, and 16.

For 1 millimeter distance the sensitivity of the arrangement for stream velocities up to 20 meters per second is rather strong. Between 20 and 75 meters per second the sensitivity drops to a small fraction. For the larger distances of electrodes the sensitivity is distributed more evenly over the entire field of calibration curves as can be seen clearly in particular from figure 16 for a distance of the electrodes of 3 millimeters.

The families of calibration curves of figures 14, 15, and 16 are sufficient to determine quantitatively the sensitivity of the anemometer to fluctuations of the flow velocity. This is carried out in the following chapter.

The junction of the calibration curves with the abscissa was here and in several following diagrams not taken so exactly as in the former ones since it was no longer of interest.

5. ABOUT THE THEORETICAL AND EXPERIMENTAL DETERMINATION OF

THE SENSITIVITY TO FLOW FLUCTUATION OF THE LEAKAGE

CURRENT ANEMOMETER

In order to see whether measurements of fluctuations of the desired accuracy are possible by means of the anemometer and under what operating conditions the prospects are most favorable, the sensitivity to fluctuation of the leakage current anemometer had to be determined. Therefore a theory of the sensitivity to fluctuation of the anemometer was developed and numerically evaluated (reference 3).

The theory of the calibration curves developed in reference 1 gives for the drop ΔJ of the current below the current J_0 at zero velocity for the stream velocity v_B :

$$\frac{\Delta J}{J_0} = \frac{v_B}{eE} \frac{6\pi\eta r}{\alpha H} \left(1 - \frac{J_F}{J_0} \right) \quad (1)$$

Therein represented, as was partly mentioned already,

ΔJ drop in current with flow

J_0 current through gap with no flow

v_B stream velocity in centimeters per second

e electric charge of ions

E macroscopic field strength

η viscosity of gas

r radius of effective cross section of gap molecules

α electronic ionization coefficient

L distance of electrodes

H height of electrodes (for rectangular cross section,
width of electrodes 1 centimeter)

J_F spurious current

According to reference 1 one should substitute for the function $\psi(\alpha h)$:

$$\psi(\alpha h) = \frac{\frac{(\alpha h)^2}{2} \lambda^{\alpha h}}{\lambda^{\alpha h}(\alpha h - 1) + 1} - 1 \quad (2)$$

The function is reduced for larger distances of the electrodes with $\alpha h \gg 1$ and $\left(\frac{1}{\alpha h}\right)^2 \ll 1$ to

$$\psi(\alpha h) \approx \frac{\alpha h}{2} - 1 \quad (3)$$

and the "influence function" $\frac{\psi(\alpha h)}{\alpha h}$ becomes in approximation

$$\frac{\psi(\alpha h)}{\alpha h} \approx \frac{\frac{\alpha h}{2} - 1}{\alpha h} \approx \frac{1}{2} \frac{h}{H} \quad (4)$$

If one defines a relative anemometric sensitivity to fluctuation (J amperage, v stream velocity, ΔJ change of J for change of v by Δv) as

$$\eta_{vel.} = \frac{\Delta F/F}{\Delta v/v} \quad (5)$$

an absolute sensitivity to fluctuation as

$$\eta_{abs.} = \frac{\Delta F/F}{\Delta v} \text{ 1/cm/sec} \quad (6)$$

and a fluctuation ratio $\eta_S = \frac{\Delta F}{\Delta v}$ as

$$\eta_S = \frac{\Delta F}{\Delta v} \frac{\text{Amp.}}{\text{cm/sec}} \quad (7)$$

one has according to the theory for the absolute amount of the relative anemometric sensitivity to fluctuation

$$\left| \eta_{vel.} \right| = \frac{\psi(\alpha h)}{\alpha h} \frac{v_B}{v_{ll}} \left[1 + \frac{v_B}{v_{ll}} \frac{\psi(\alpha h)}{\alpha h} \right] \text{ or} \quad (8)$$

in second - lowest approximation:

$$|\eta_{vel.}| = \frac{\psi(\alpha h)}{\alpha H} \frac{v_B}{v_{ll}}$$

with

$$v_{ll} = \frac{eE}{6\pi\eta r}$$

the other defined magnitudes follow therefrom.

Numerically there resulted for instance for a distance of electrodes of 3 millimeters, an operating voltage of 80 percent of the ignition voltage and a mean flow velocity of 100 meters per second a relative sensitivity to fluctuation of 15.3 percent.

This result signifies that for an absolute sensitivity to fluctuation of the order of magnitude 10^{-4} to 10^{-5} and with amperages of the order of magnitude $1 \dots 1/10$ μ amperes there results a fluctuation ratio of 10^{-11} to 10^{-12} ; that is with fluctuations of the air flow of 1 meter per second there results fluctuations of the electric current, the amplification of which for turbulence frequencies appears barely discussable.

According to this result it seemed advantageous to supplement the theoretical investigation of the sensitivity to fluctuation by an experimental investigation. Therefore the families of calibration curves of figures 14, 15, and 16 were taken and the "voltage curves" of figures 17, 18, and 19 determined from them.

The curves give for fixed voltage the amperage as a function of the stream velocity. The steepness of the curve is a measure for the fluctuation ratio. It decreases with increasing stream velocity. For smaller voltages and distances of electrodes it finally tends toward a constant value.

With increasing mean stream velocities the conditions become the more favorable the more the separation of electrodes and the fixed voltage increase. This can be seen particularly clearly by comparing figure 17 with figure 19. For 3 millimeters separation of electrodes (fig. 19) one has a sufficient fluctuation ratio for every stream velocity from 0 to 120 meters per second. With smaller mean stream velocities the fluctuation ratio increases considerably here also.

This is not synonymous with an increase of the relative anemometric sensitivity to fluctuation toward smaller values of the mean stream velocities and a decrease toward large ones. In figure 20 and figure 21 the relative anemometric sensitivities to fluctuation

of the two arrangements of 2 millimeters and 3 millimeters distance of electrodes are plotted. The points marked are calculated values. In spite of the variations in single cases it is obvious that the plotted average values of the curves, in particular for the lower voltages, increase monotonously with rising stream velocity. This is true to the theoretical expectation: (reference 3 equation (11) and reference 3 p. 8). The theory is supposed to agree according to its

hypothesis (homogeneous symmetrical field, $\dot{\gamma} = 0$; $\frac{\Delta F}{F} \ll 1$, $\frac{\Delta v}{v} \ll 1$)

the better the smaller voltages, the larger the stream velocities and the smaller the distances of electrodes.

Viewed absolutely, the measured values of the relative sensitivities to fluctuation are slightly higher than the calculated values. For instance, the values for distances of the electrodes of 2 millimeters and 3 millimeters are of the order of magnitude of one-tenth to one (figs. 20 and 21).

Figure 22 gives the absolute sensitivity to fluctuation for 3 millimeters distance of electrodes determined from measurements. According to theory it should be independent of the stream velocity and should increase with decreasing voltage (reference 3 equation (15)). The latter statement is at least qualitatively confirmed by the experiment: the first conclusion of the theory should agree the better the larger v_B as shown also in figure 22.

The result of the experimental determination of the sensitivity of fluctuation is therefore that one can, for mean amperages of the leakage current of the order of magnitude between $1 \mu A$ and $\frac{1}{100} \mu A$ for fluctuations of turbulence of the flow velocity, count on current fluctuations of the order of magnitude of 10^{-9} to 10^{-11} amperes. These are fluctuations which, for turbulence frequencies, are in principle controllable by the amplifying technique. Of course one must not fail to recognize that the tests require that the entire measuring apparatus and the voltage supplies are required to be very steady and free of disturbances and that special consideration must be given to reducing the capacities resulting from the construction of the apparatus.

6. EXPERIMENTS WITH OTHER MATERIALS FOR ELECTRODES

As set forth in the last chapter, there results for UV-radiation for platinum electrodes of 1 millimeter ϕ there is a basic possibility of examining minute fluctuations in the velocity of flow of air; however, the requirements for freedom from disturbances and for stability are extremely heavy. Thus the problem arises whether

it is not possible, by selection of different materials for the electrodes or by different shapes of the electrodes, to create different conditions where the requirements of constancy of the voltage source and of freedom from disturbance for the entire arrangement are not so extreme. In this chapter a few results of tests with zinc and with aluminum electrodes will be reported.

Earlier tests were made with nickel electrodes: no difference between the calibration curves for nickel electrodes and for platinum electrodes could be ascertained. In figure 23 the calibration curves of the dark current were taken for zinc electrodes of 1 millimeter ϕ for three different distances of the electrodes. As far as form is concerned, their course does not show any essential difference from the corresponding curves for platinum electrodes. The order of magnitude of the currents also is entirely identical. The course of the calibration curve for 3 millimeters distance of electrodes which is qualitatively slightly different may depend on reasons as they were stated in chapter three.

Figure 24 shows a family of calibration curves with zinc electrodes, figure 25, the corresponding voltage curves. The conditions are quite similar to those for platinum electrodes, as a comparison with the voltage curves of figure 19 will show.

It shall be noted here that the differences in detail of the various curves which bear the same designation are caused by the fact that identically labeled curves of this paper can be taken with different spurious currents as the lamp used to indicate the spark gap must be readjusted each time. Although one endeavors to bring the cathode exactly into the outer focal plane of the reflector, one succeeds practically only to a more or less good degree.

Since zinc is considerably less stable in air than platinum and since it does not offer any essential advantages, compared with platinum, as shown in the figures, platinum will be preferable.

Another test was made with aluminum electrodes. The results are plotted in figure 26. For aluminum also there were no advantages compared with platinum.

7. EXPERIMENTS IN A STRONGLY INHOMOGENEOUS FIELD

The results of the treatise I (reference 1) had shown that compared with the homogeneous field, the inhomogeneous field condition offers under certain circumstances much greater possibilities for influencing the

results. This fact gave rise to the taking of fields of calibration curves under conditions of a strongly inhomogeneous field. Nevertheless, one took pains to keep the dimensions for the arrangement of electrodes very small.

Thus an arrangement was selected with an iridium wire of 1/2 millimeter ϕ as anode and a fine nickel foil as cathode. Fields of calibration curves for distances of 2, 3, and 4 millimeters were taken (figs. 27, 28, and 29).

There appears at once the remarkable result that the currents obtained under otherwise equal conditions are about five times larger than for the arrangements discussed so far. However, an attentive observer will notice immediately that the voltages involved here lie between the "threshold voltage" of the glow discharge and the breakdown voltage.

The calibration curves of figures 27, 28, and 29 are therefore for the most part calibration curves of a radiating glow discharge. Only for quite small amperages below the threshold voltage does one deal with Townsend currents. For the present conditions (compare chapter three) the two forms of discharge which are of a different character will, circumstances permitting, imperceptibly change into one another. The glow discharge can, therefore, be influenced by blowing in the same way as the Townsend discharge; the fields of calibration curves prove this fact. Therefore, the difference will no longer be specifically pointed out in the following consideration.

The fivefold increase of the amperage obtainable as a maximum in figures 27, 28, and 29 is not necessarily an improvement concerning the anemometric sensitivity to fluctuation. This is shown by figures 30, 31, and 32 in which the voltage curves of the fields of calibration curves of figures 27, 28, and 29 are plotted. Figure 33 shows the evaluation of these figures with respect to the anemometric sensitivity of fluctuation, for the voltage values held at 8 kv, 10 kv, and 12 kv. Here also the relative anemometric sensitivity to fluctuation increases with the stream velocity.

A comparison with the corresponding sensitivities to fluctuation for platinum electrodes of 1 millimeter ϕ and less inhomogeneous conditions of the field for the same distance of electrodes (3 mm) results, if one considers both figures 33 and 21. The relative sensitivity to fluctuation in the strongly inhomogeneous field is more unfavorable by about one power of ten than for the symmetrical arrangement of the electrodes of figure 21. Thus, as far as the anemometric sensitivity to fluctuation is concerned, nothing is gained by the change to a strongly inhomogeneous field³. On the

³ With glow discharge.

contrary, the arrangement has become more unfavorable by one power of ten.

Figure 34 shows the absolute anemometric sensitivity to fluctuation of the arrangement. One obtains roughly for not too small free-stream velocities, similar to the theoretical requirement in the case of the homogeneous field, approximate independence of the stream velocity and a higher value for the small voltages. As results already from the last figure, and as shown by a comparison with figure 22, the absolute anemometric sensitivity to fluctuation also is more unfavorable by approximately one power of ten than the arrangements discussed in the chapters above.

The possibilities of a "one electrode anemometer" (compare reference 3 p. 17) were considered and in connection tests were made with a 1/2-millimeter thick iridium anode and a larger nickel plate (76 mm ϕ) as cathode; a larger distance between the electrodes (20 mm, 30 mm, and 40 mm) was selected.

The results of these tests are shown in figures 35, 36, and 37. One notices at once that here the amperages obtained as a maximum have again dropped to a relatively small amount, namely, once again to an order of magnitude of 10 μ A. Furthermore, for the larger distances of electrodes it is striking that the calibration curves partly intersect. However, this phenomenon and its consequences will not be discussed more closely here.

The corresponding voltage curves are plotted in figures 38, 39, and 40. In figure 39 in particular the ambiguity stands out strongly. Also, it would have to be investigated whether or not for these arrangements, in particular for the higher voltages and larger amperages, a transition to the glow discharge takes place which burns even after the radiation has been discontinued. Since these questions are, for the moment, not very interesting, they were not further elaborated.

8. PREIONIZATION BY MEANS OF X-RAYS

It appears interesting to determine whether, circumstances permitting, more favorable conditions could be obtained by use of a modern X-ray tube than by UV-radiation. Figure 41 and 42 yield the first measurements taken some time before with an old X-ray tube. The amperages that were here obtained as a maximum lie according to approximate calculation at about 5×10^{-7} amperes.

An essential increase of the amperage was obtained with a Müller High Performance Metallix Tube (type No. 25213/01, filter

drive type No. 37401, maximum voltage 60 kv peak, maximum permissible continuous load in watts - 800 with half wave input from a Grätz - rectifier on 1000 with constant direct current) which was operated with 50 kv and 10 mA and is provided with four holes for the exit of the X-rays (fully protected tube). It was operated with a disk of 1.2 centimeters ϕ and the distance of the electrodes from the anticathode was 6.2 centimeters.

By means of this tube the families of calibration curves of figures 43, 44, and 45 were taken. For platinum electrodes of 1 millimeter ϕ and distances of electrodes of 2 and 3 millimeters one obtains amperages which again reach a maximum of 10 μ A exactly as they could be obtained with UV-radiation for the most favorable conditions. For the larger distance of electrodes the amperage is lower by about one half.

The voltage curves pertaining to the electrode distances 2 and 3 millimeters are shown in figures 46 and 47, the voltage curves pertaining to the large distance of electrodes of 6 millimeters are distributed on two charts (figs. 48 and 49); figure 48 shows the lower, figure 49 the high voltages. The steepness of the curves, in particular for the lower voltages, is striking.

Another earlier picture shall be given here of calibration curves with zinc electrodes of 1 millimeter ϕ and 3 millimeters distance, this time, however, with a preionization by X-rays which are produced for 30 kv and 5 mA tube current (fig. 50). No new points of view result.

9. SUMMARY

In earlier treatises it was shown that by taking groups of calibration curves with initial radiation by UV-lamps, by X-rays and with radio-active preparations, as well as developing a theory based on the concepts of gas kinetics, that the dark current discharge can be utilized anemometrically (references 1 and 2).

From the aerodynamic point of view the sizes of the electrodes were still about 1000 times too large. The currents were about 10,000 times too small if one aimed at fluctuation measurements of a more delicate character.

In the present treatise a report is given about an improvement of the apparatus to about 10,000,000 times its effectiveness. With X-rays and with UV-radiation an amplification of the current of 10,000 times was obtained although the cross sections of the electrodes were, for aerodynamic reasons, reduced by about one one-thousandth. This result was obtained by development of an ellipsoidal reflector for the UV-radiation of a mercury high-pressure lamp.

With the new arrangements, families of calibration curves were taken under operating conditions of the greatest variety. By calculation of the voltage curves and of the relative and absolute anemometric sensitivities to fluctuation the operating properties of the instrument for stationary conditions were exhaustively made clear and the data for the performance of measurements of fluctuation obtained.

The tests were at first limited to UV-radiation arrangements and to arrangements with X-rays as preionizers. With respect to order of magnitude about identical conditions resulted for both kinds of preionization.

Tests with anodes of various materials showed that no material gave more favorable conditions than platinum.

Tests in strongly inhomogeneous fields for, nevertheless, very small anode - arrangements (iridium point versus fine platinum foil of 3 mm ϕ at small distance) led from the dark discharge into the radiating glow discharge. The conditions for this form of discharge also were thoroughly investigated by taking several fields of calibration curves and by calculating the voltage curves as well as the anemometric sensitivities to fluctuation. The latter proved to be more unfavorable (by one power of ten) for this arrangement than for the former ones. Nevertheless the arrangement gives at least equally favorable conditions for the measurement of fluctuations since the currents lie - viewed absolutely - by one power of ten higher.

As far as the desired measurements of fluctuation are concerned, the present treatise brings the result that it ought to be possible - in principle, at least - by using various methods, to make measurements of minute fluctuations with the devices described; on the other hand there results quantitatively that the required constance of all voltage sources as well as the merit of the amplifier for turbulent frequencies (particularly with respect to minimizing capacity) have to satisfy extremely high requirements; thus carrying out the measurement of fluctuation just about coincides with the limit of today's technical possibilities.

Translated by Mary L. Mahler
National Advisory Committee
for Aeronautics

REFERENCES

1. Fucks, W.: Über die Eignung der Vorstromentladung zur Messung von Strömungsgeschwindigkeiten von Gasen (Vorstromanemometer).
2. Schumann, W. O.: Durchbruchfeldetorke in Gasen. Springer, Berlin, 1923.
3. Fucks, W.: Theorie der Schwankungsempfindlichkeit des Vorstromanemometers.

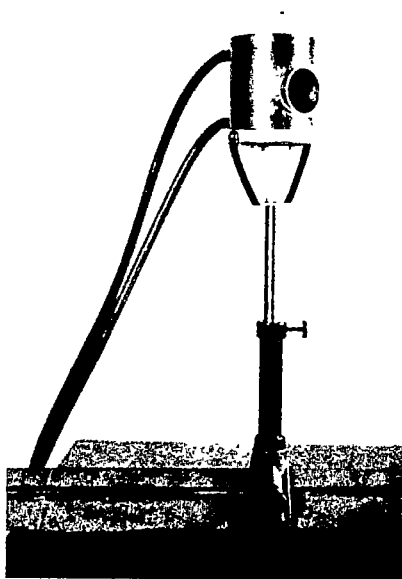


Figure 1.

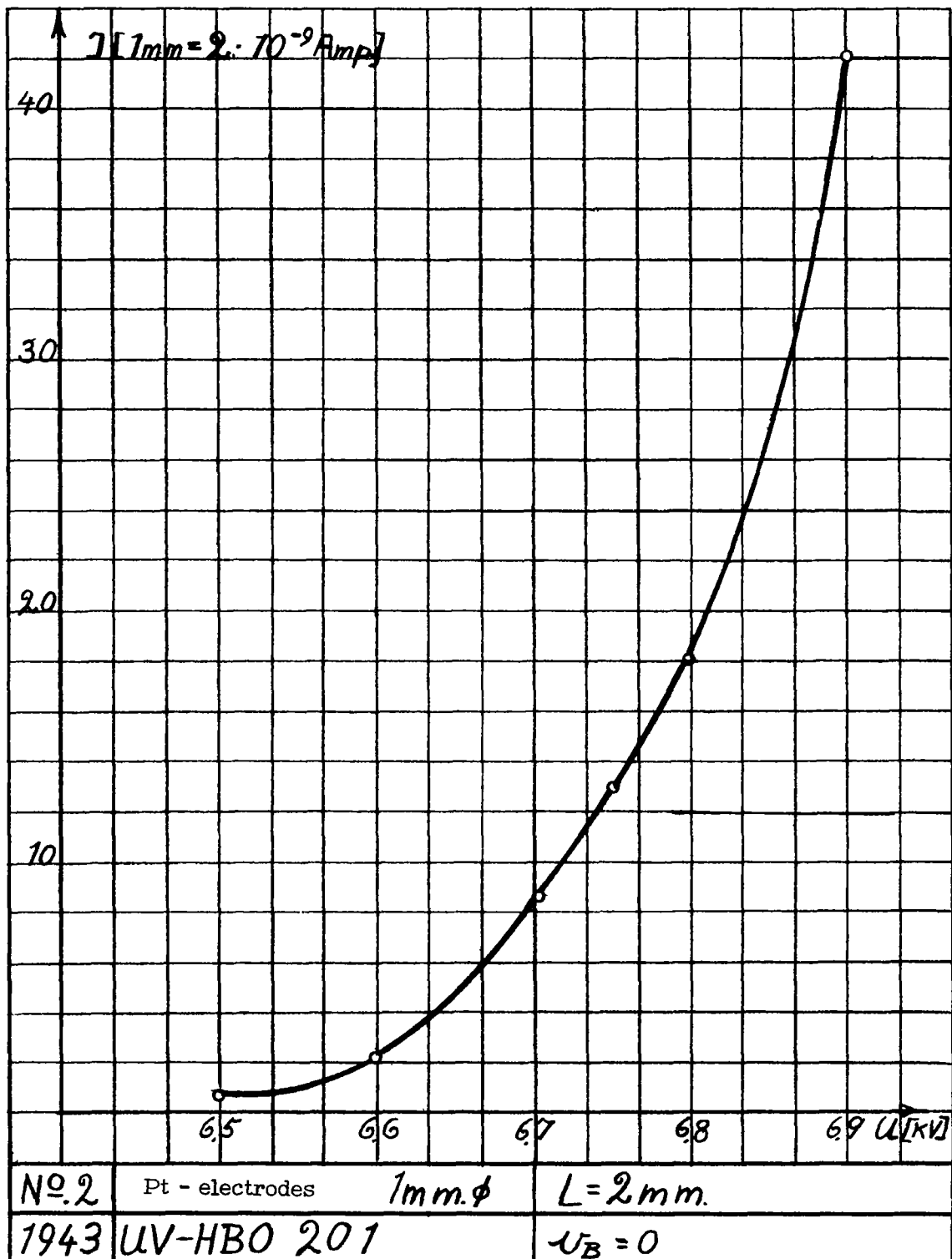


Figure 2.

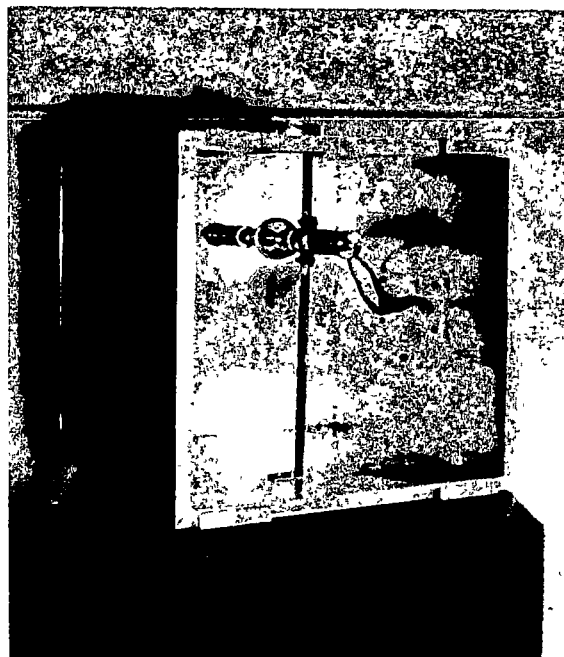


Figure 3.

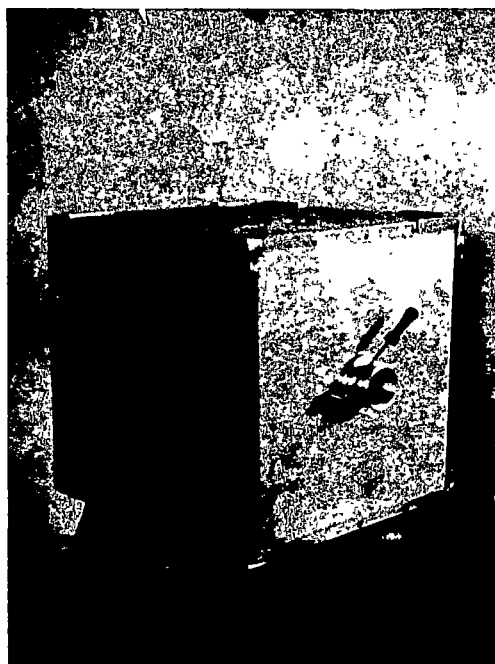


Figure 4.

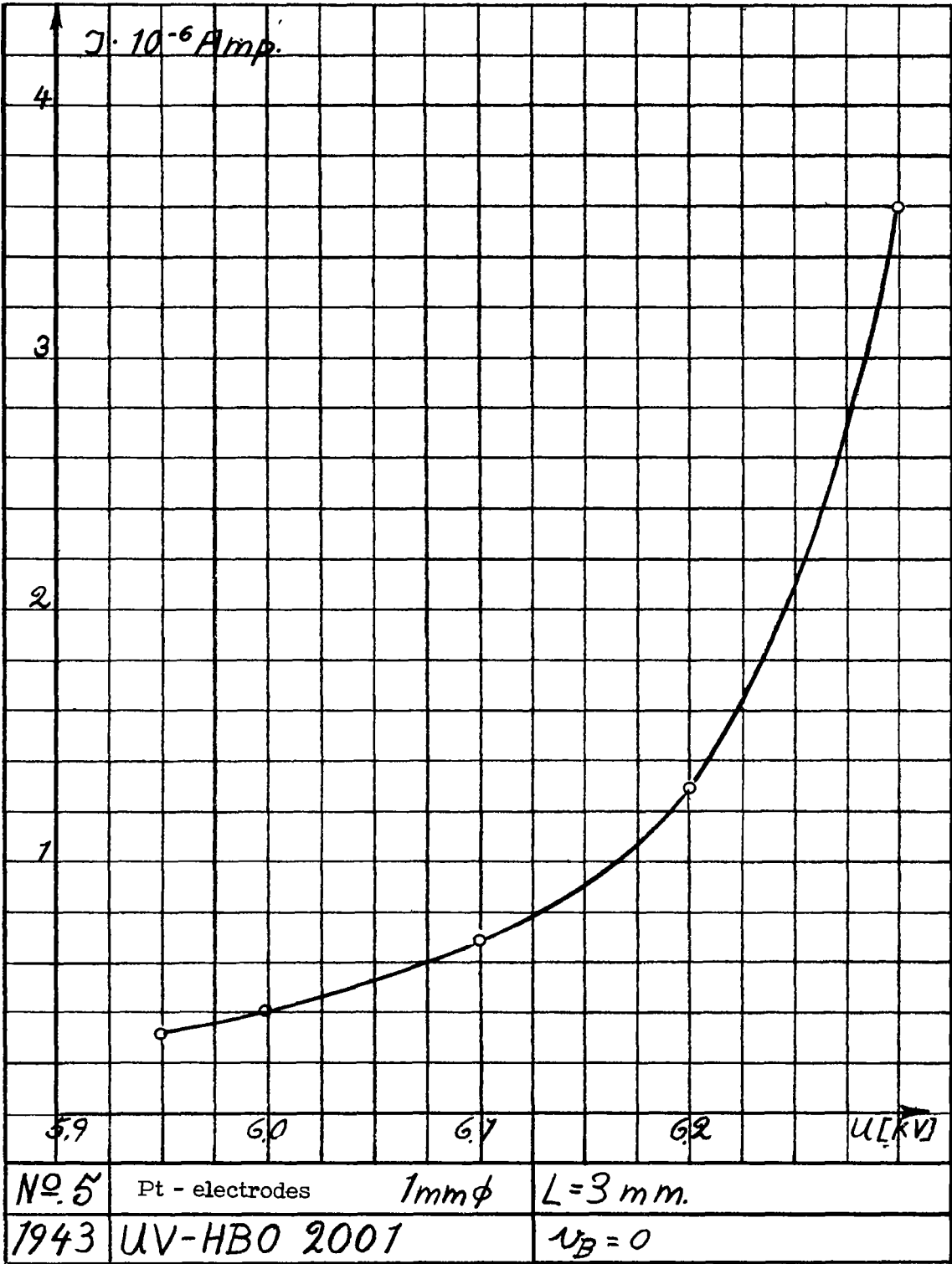


Figure 5.

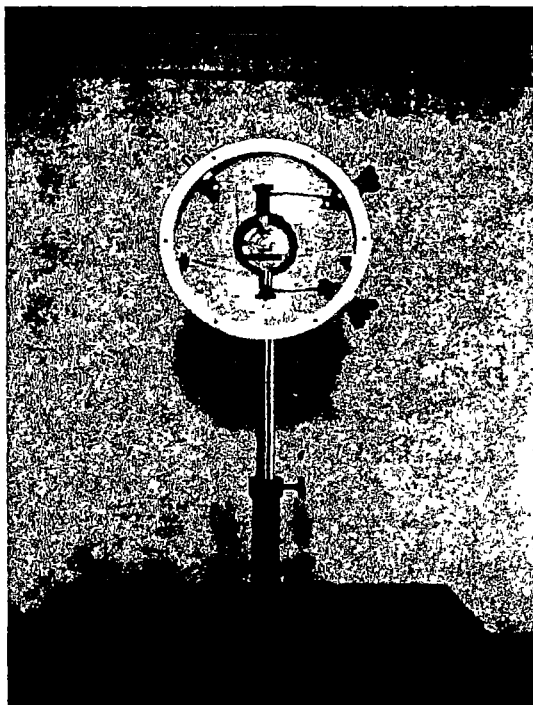


Figure 6a

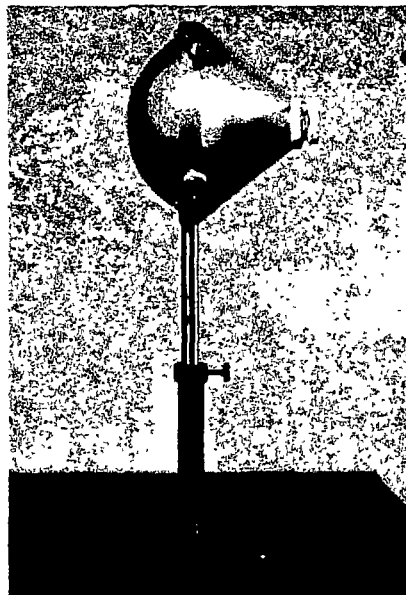


Figure 6b

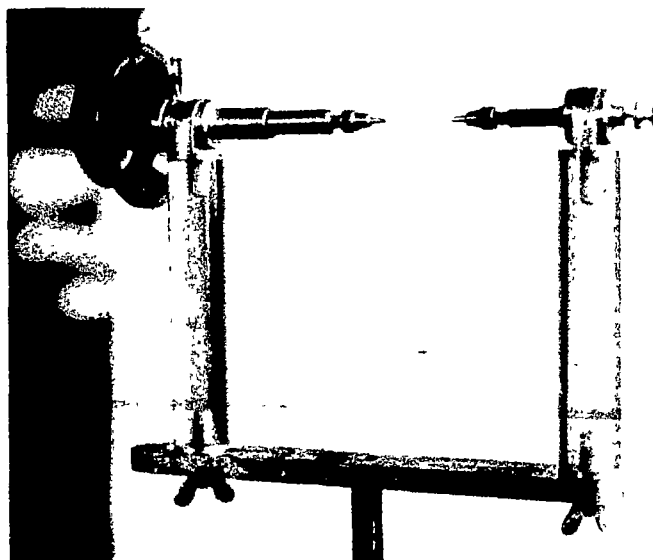


Figure 7.

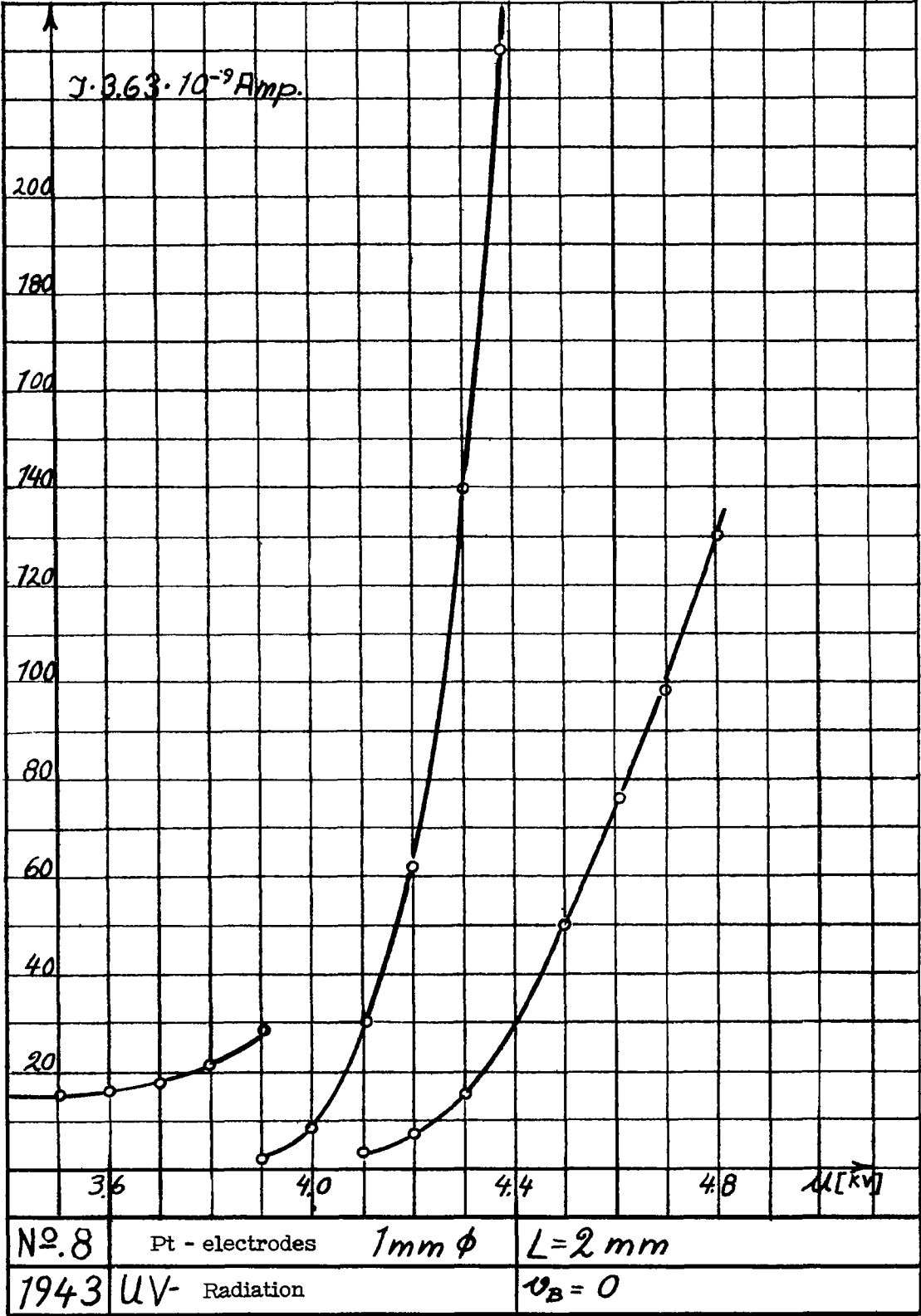


Figure 8.

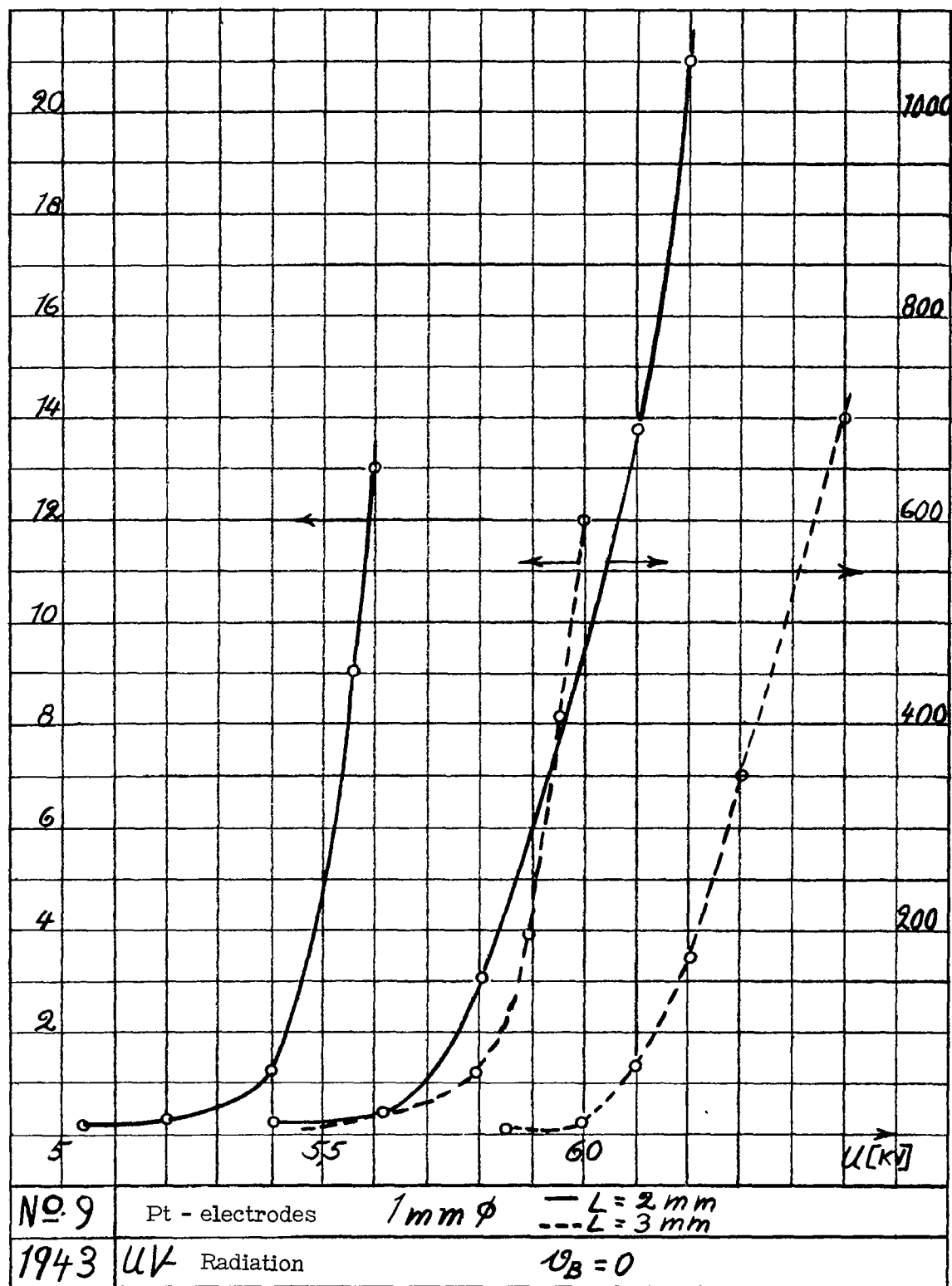


Figure 9.

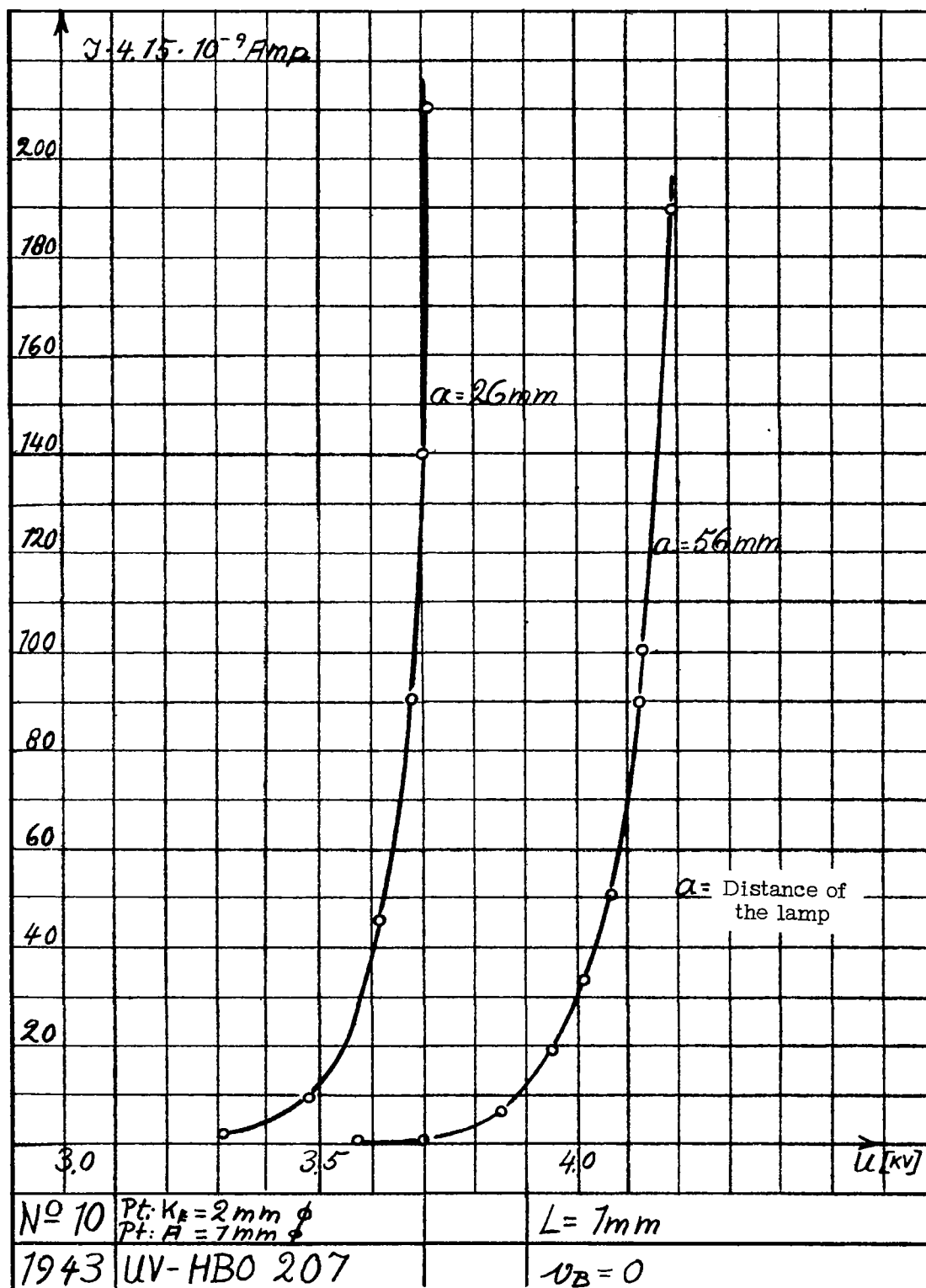


Figure 10.

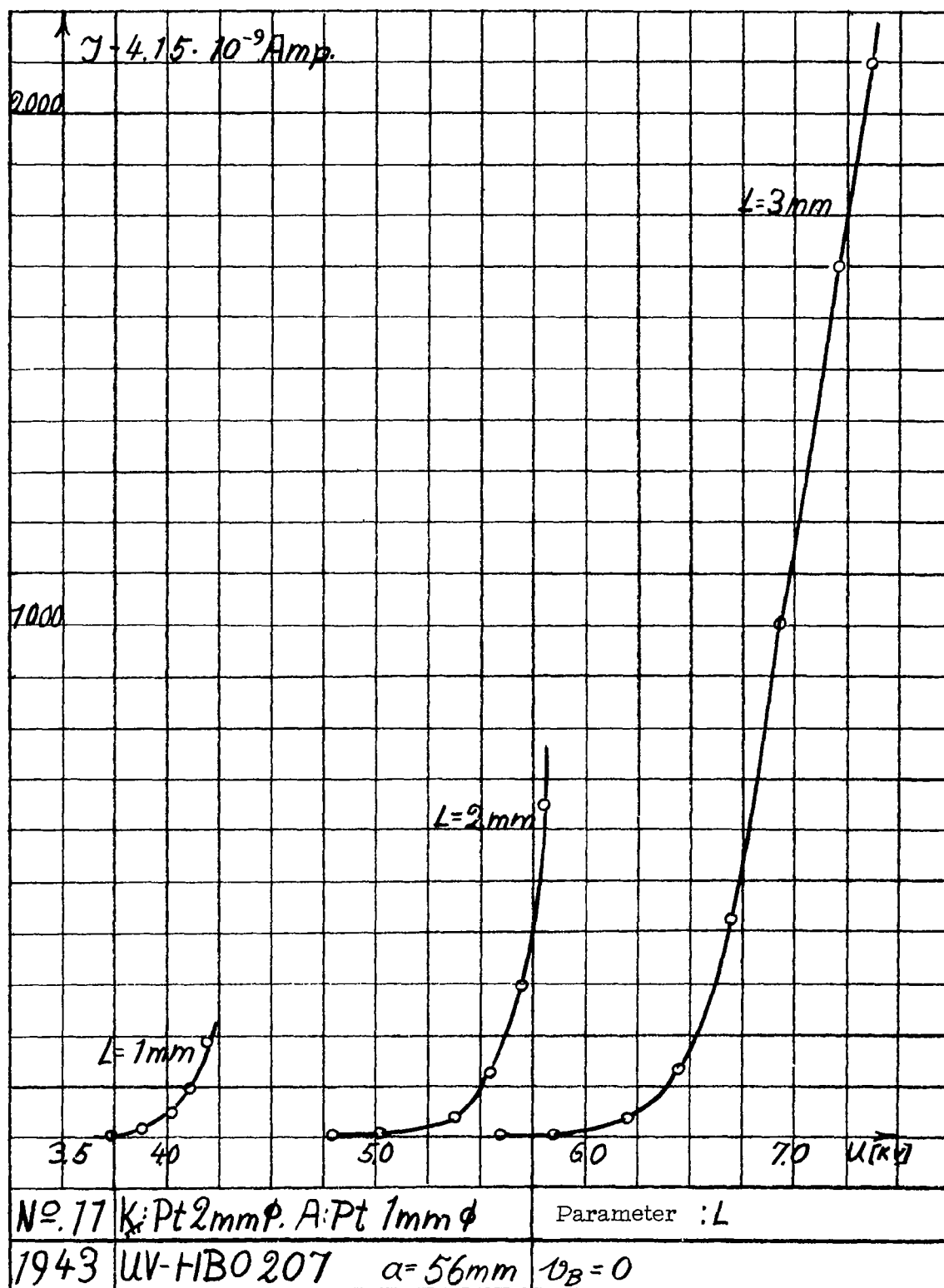


Figure 11.

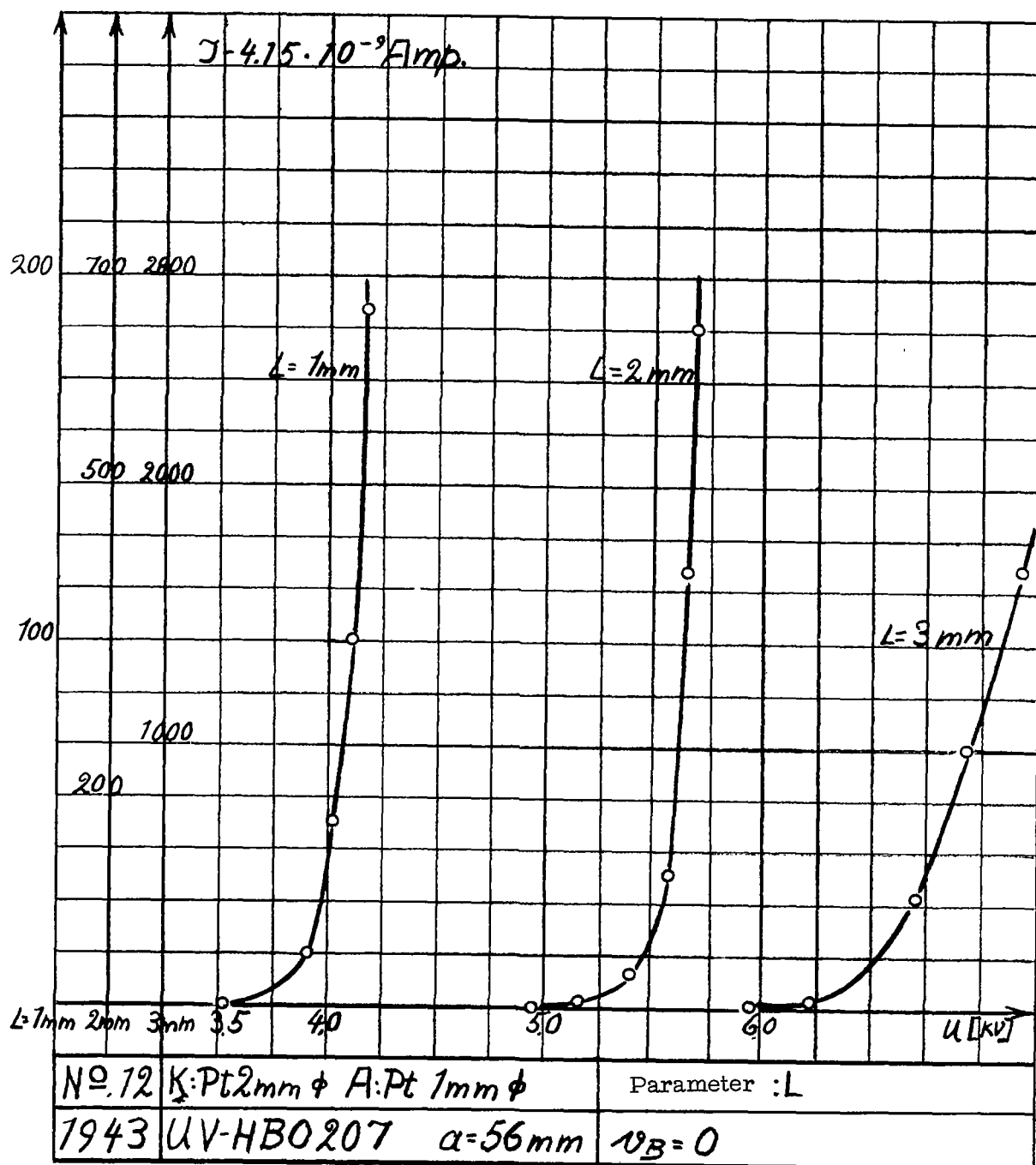


Figure 12.

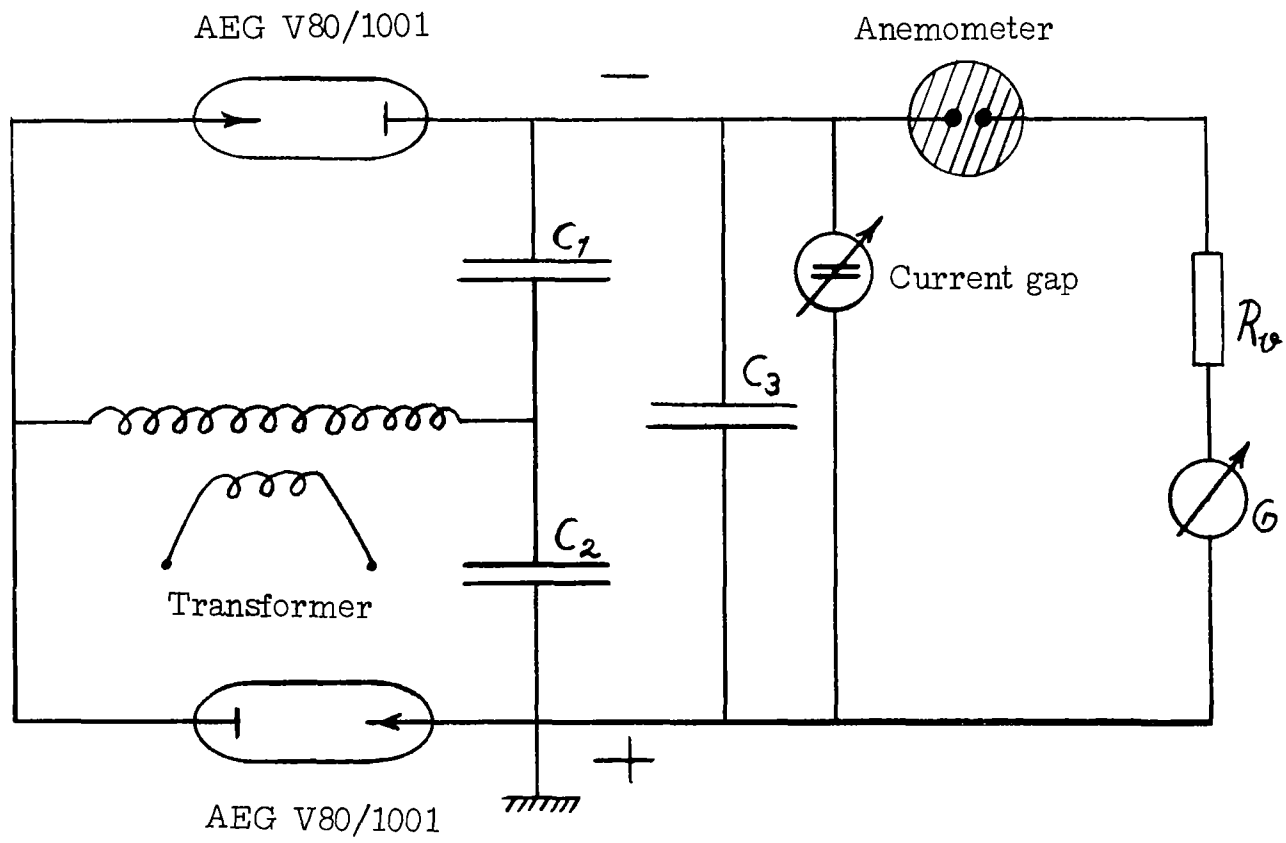


Figure 13.

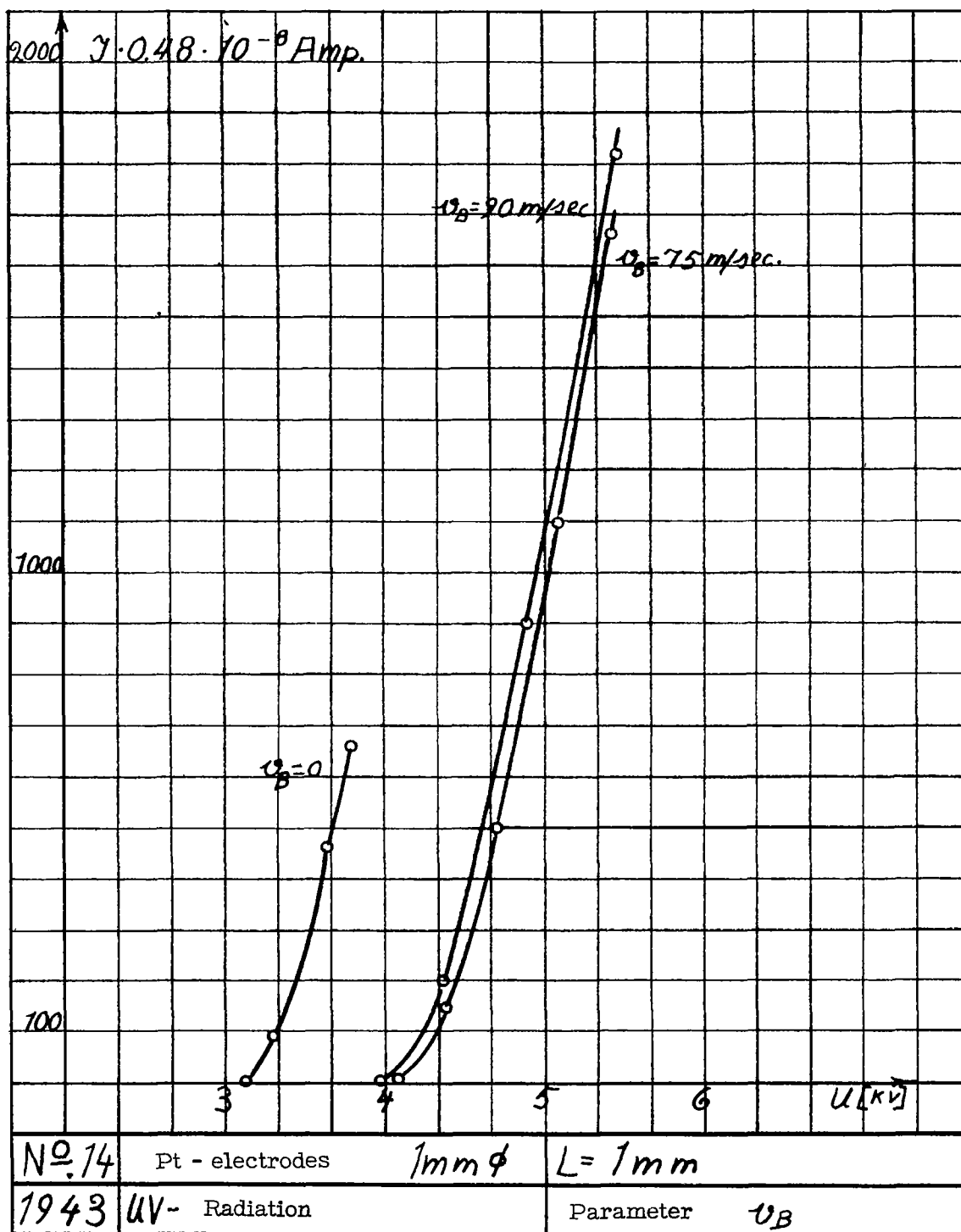


Figure 14.

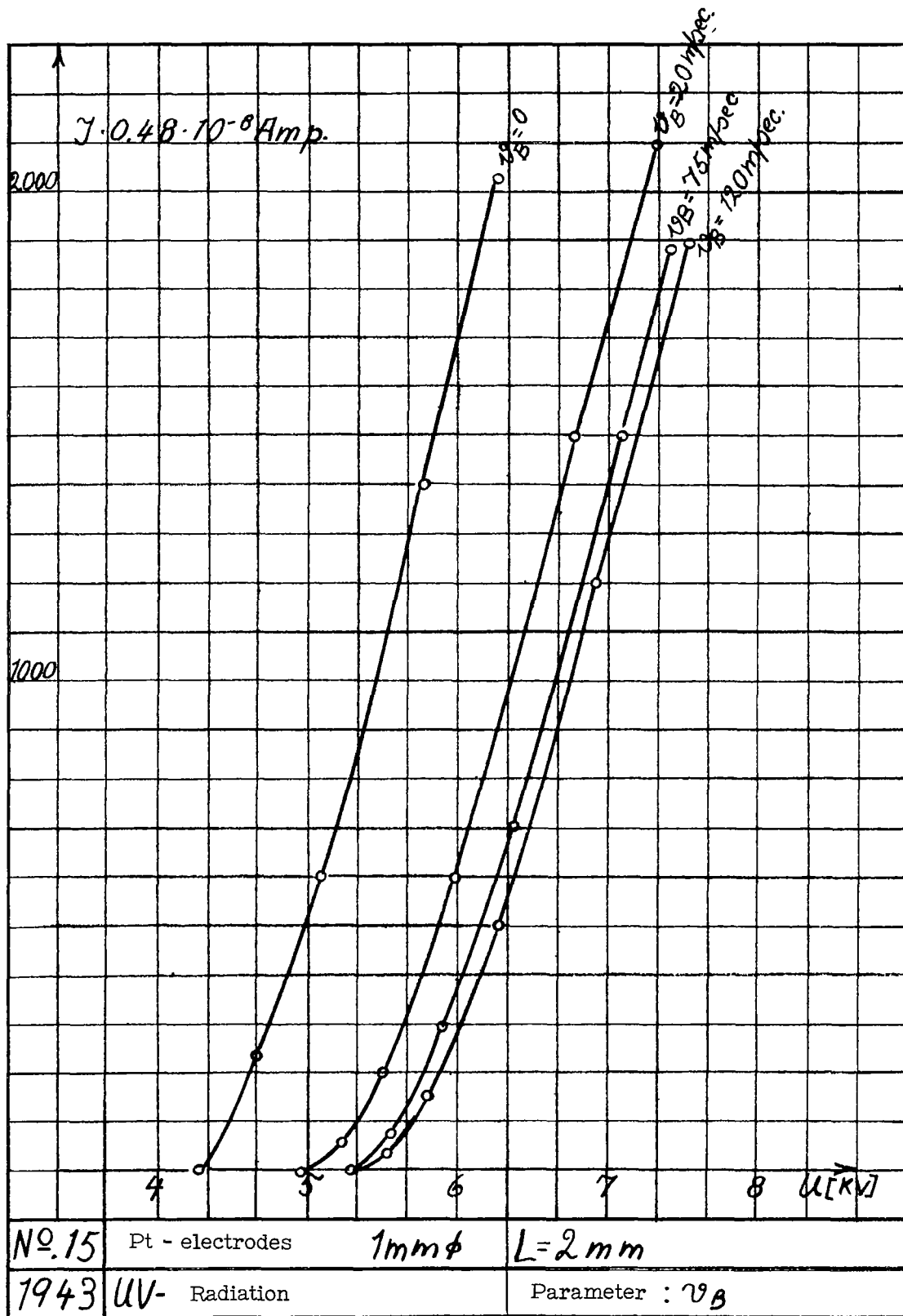


Figure 15.

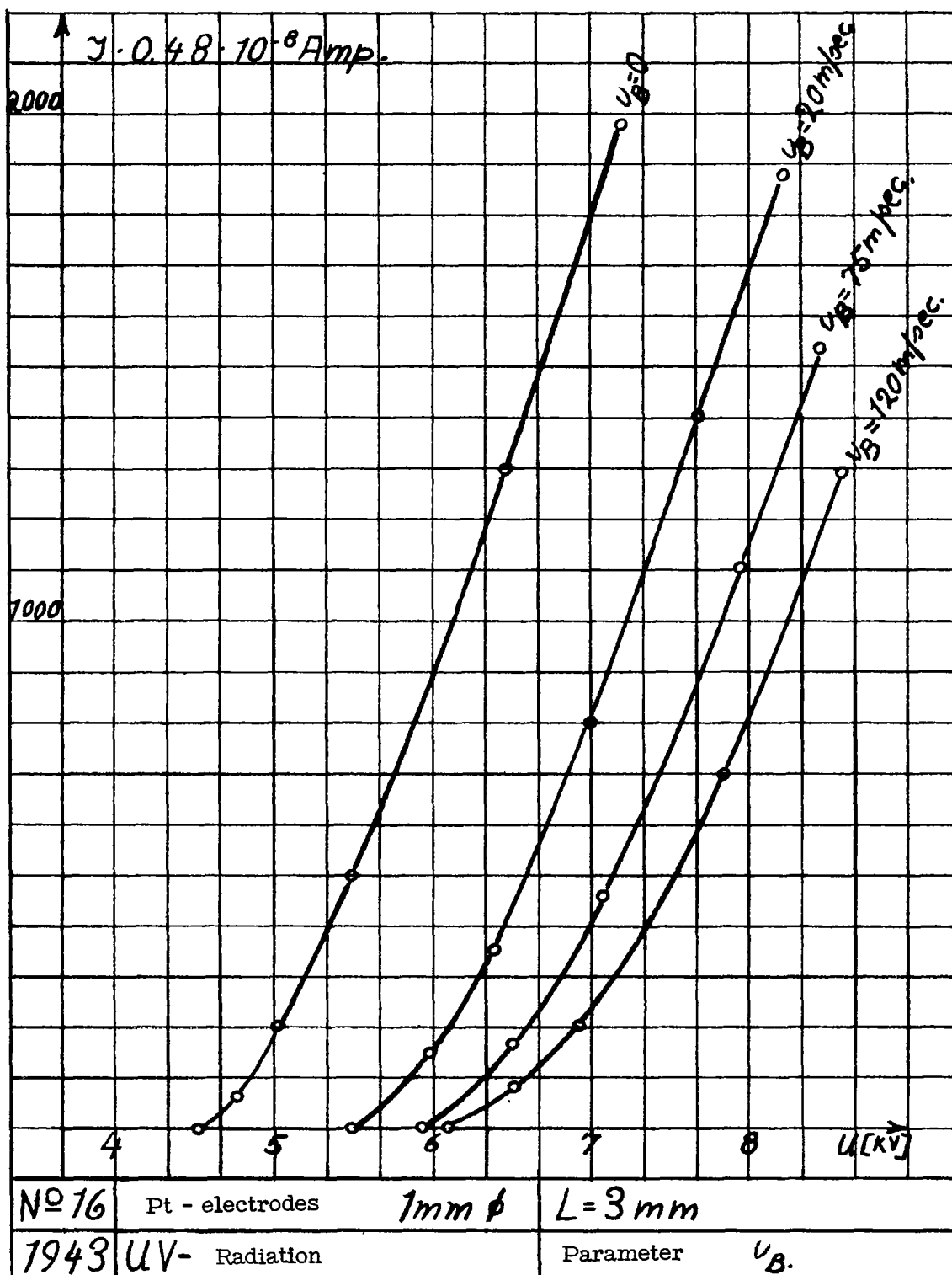


Figure 16.

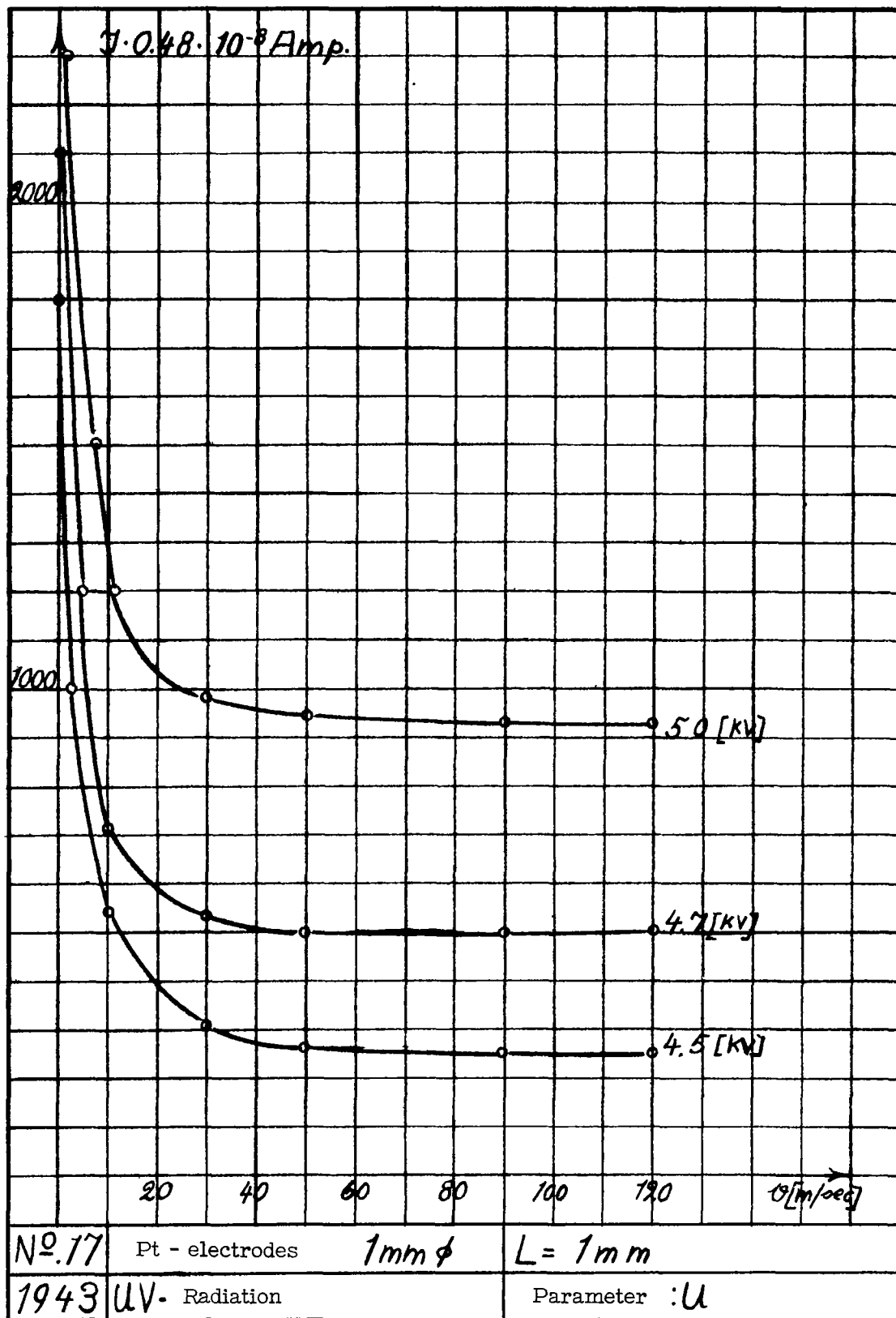


Figure 17.

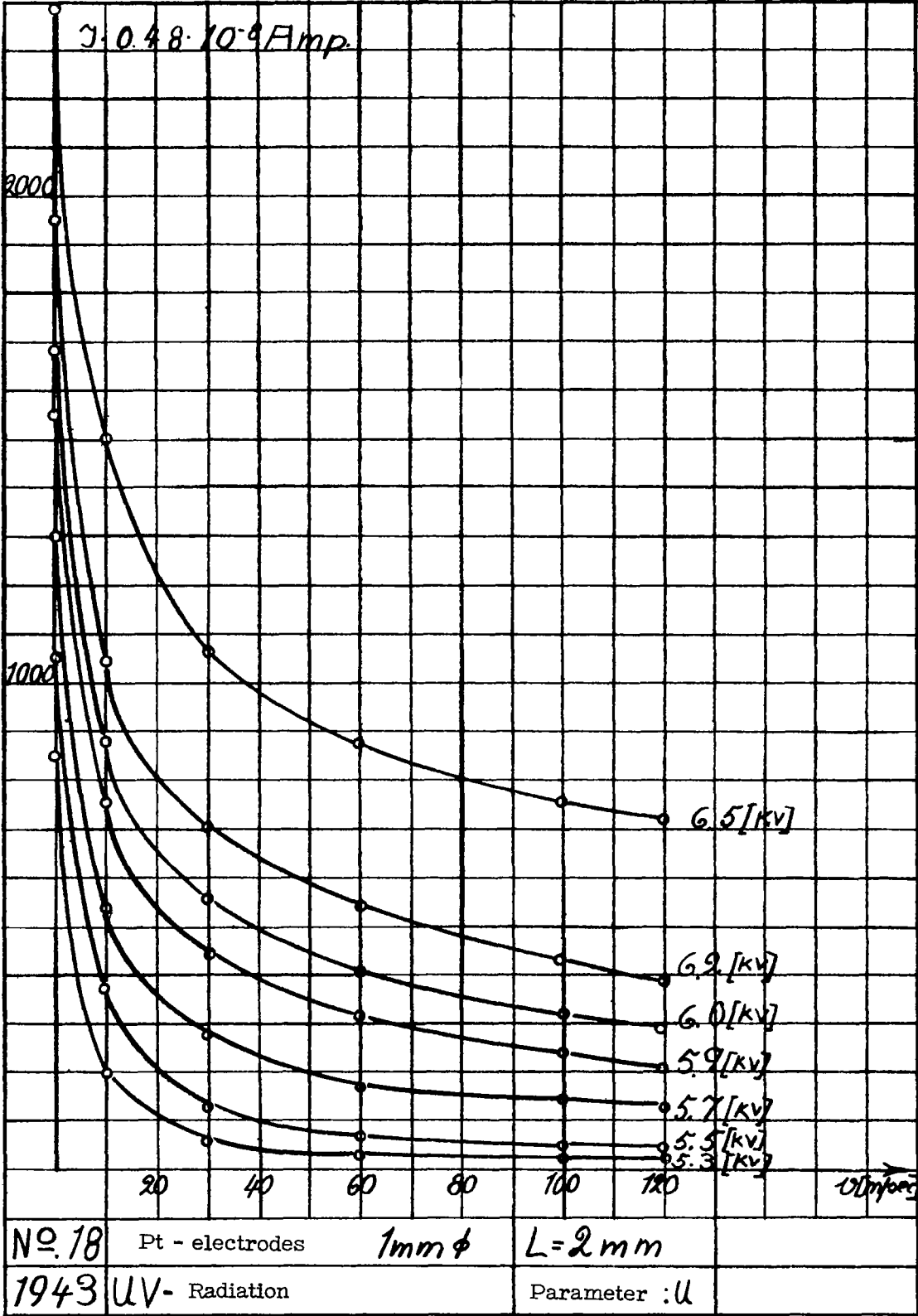


Figure 18.

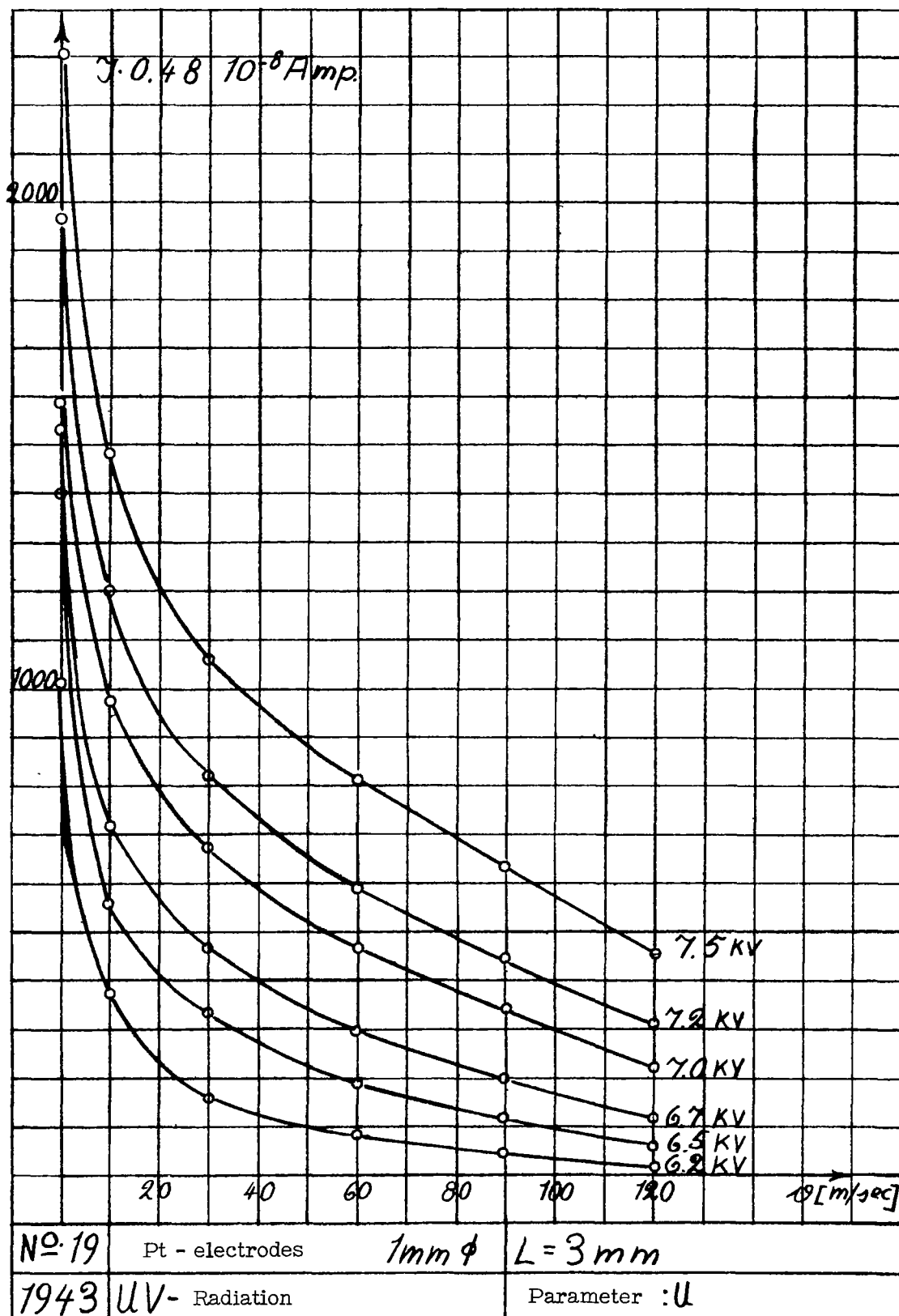


Figure 19.

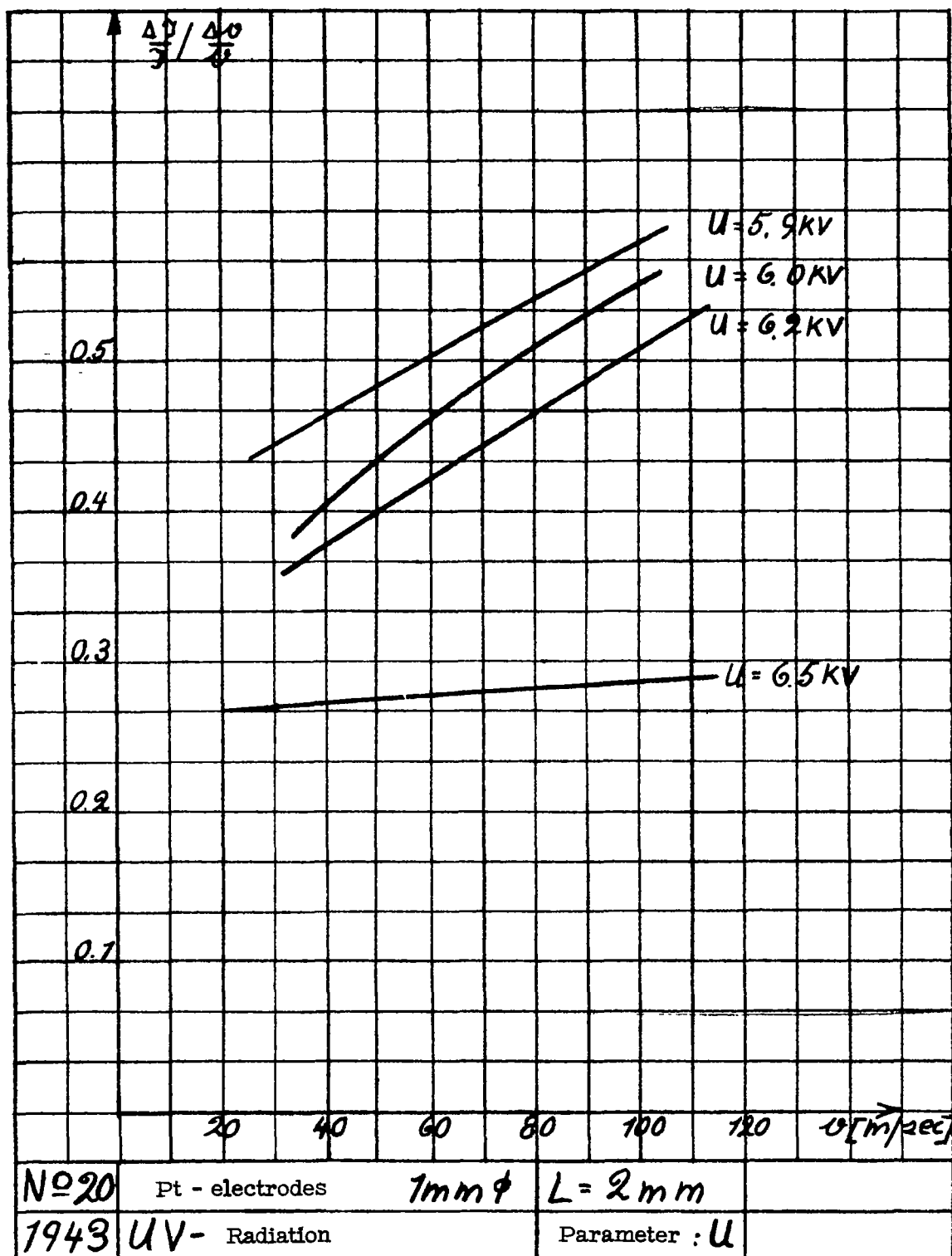


Figure 20.

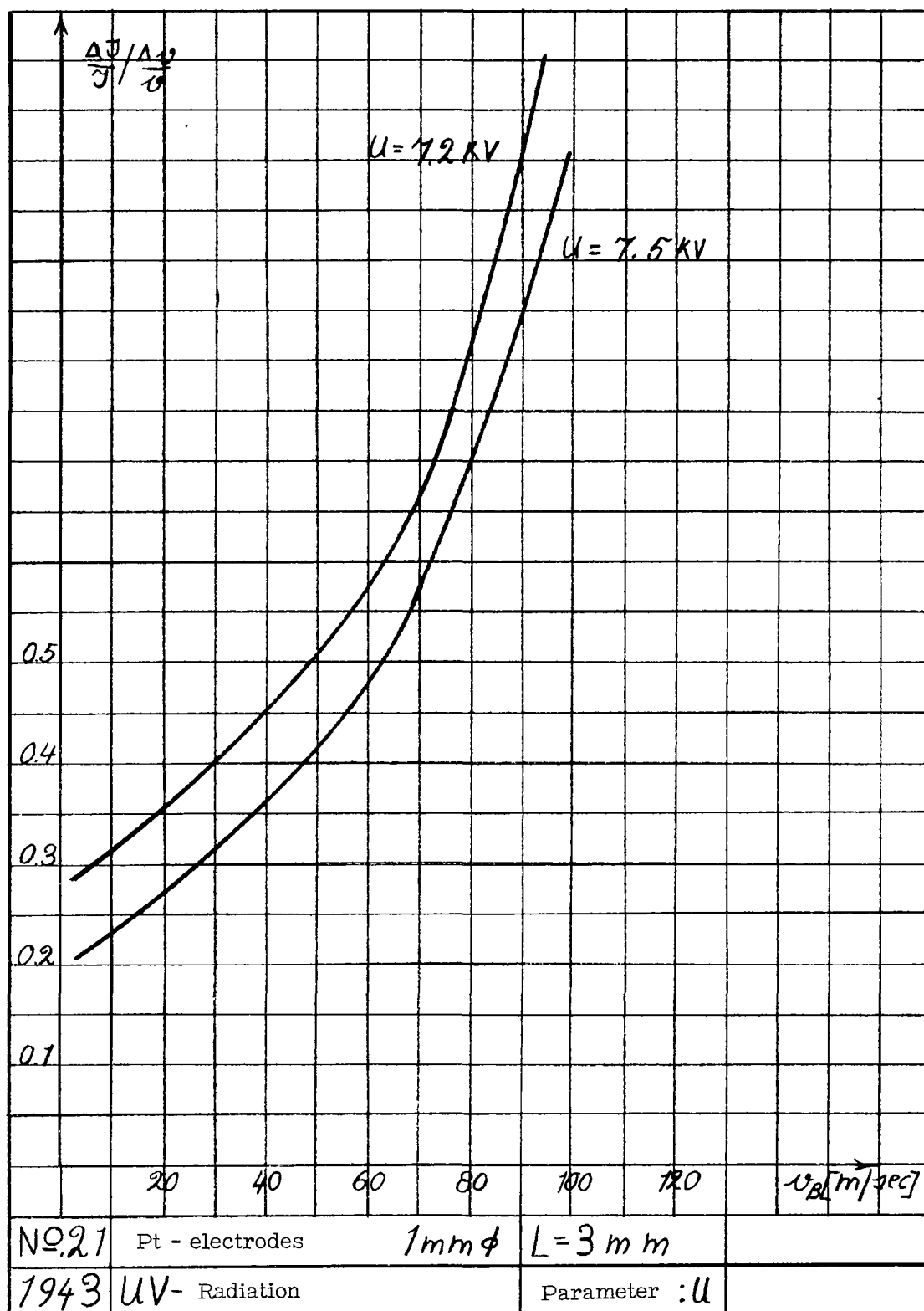


Figure 21.

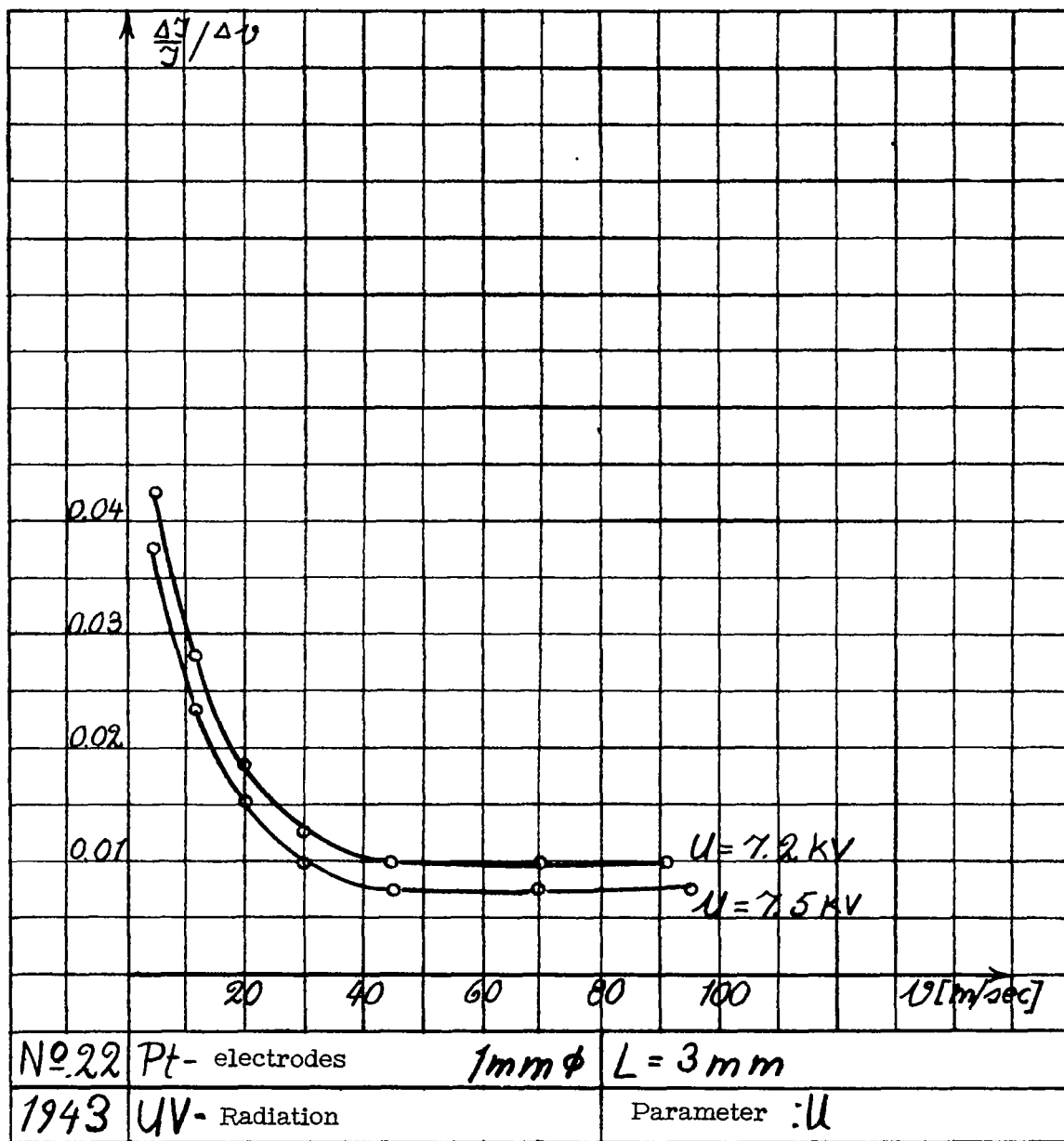


Figure 22.

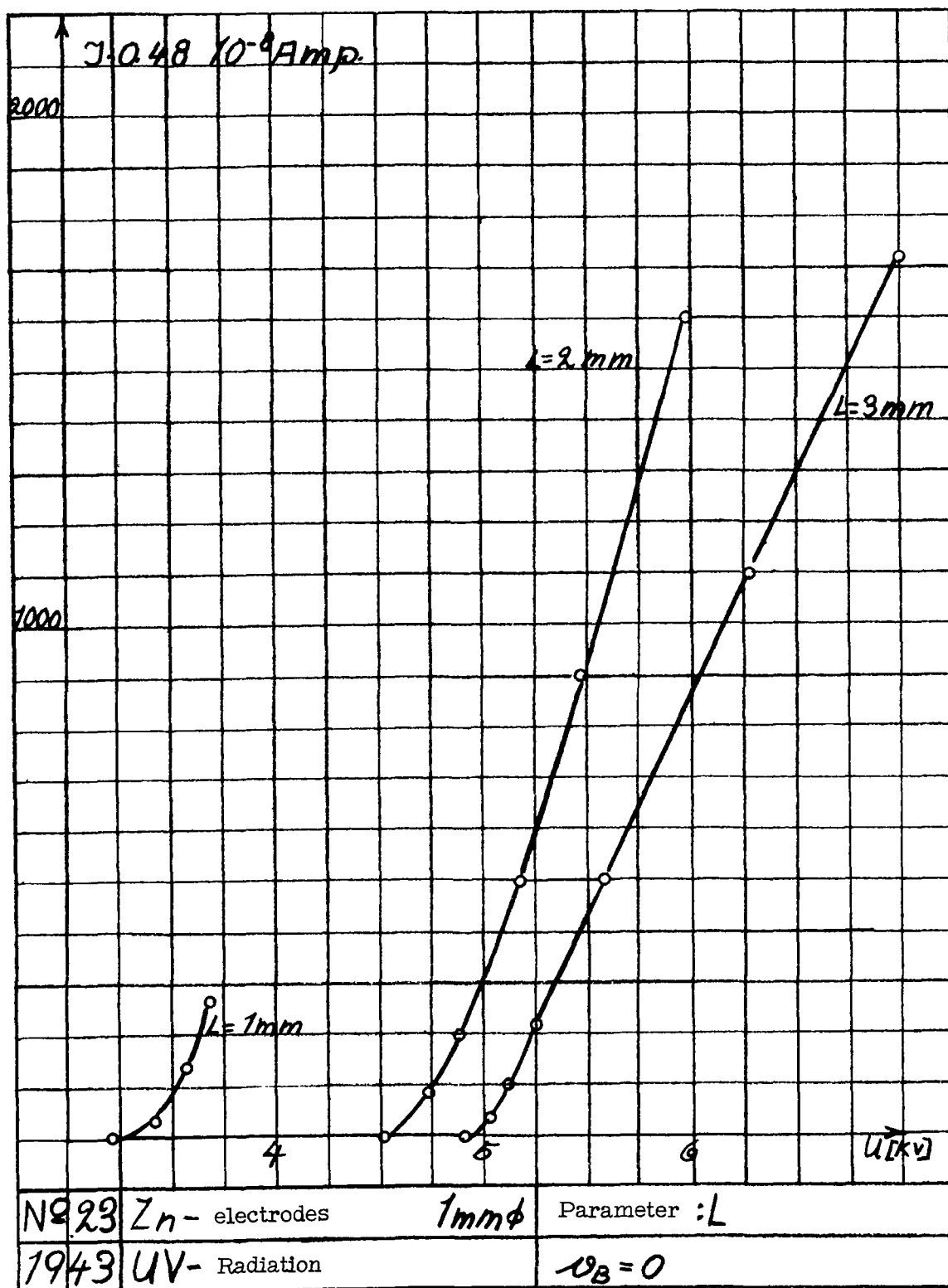


Figure 23.

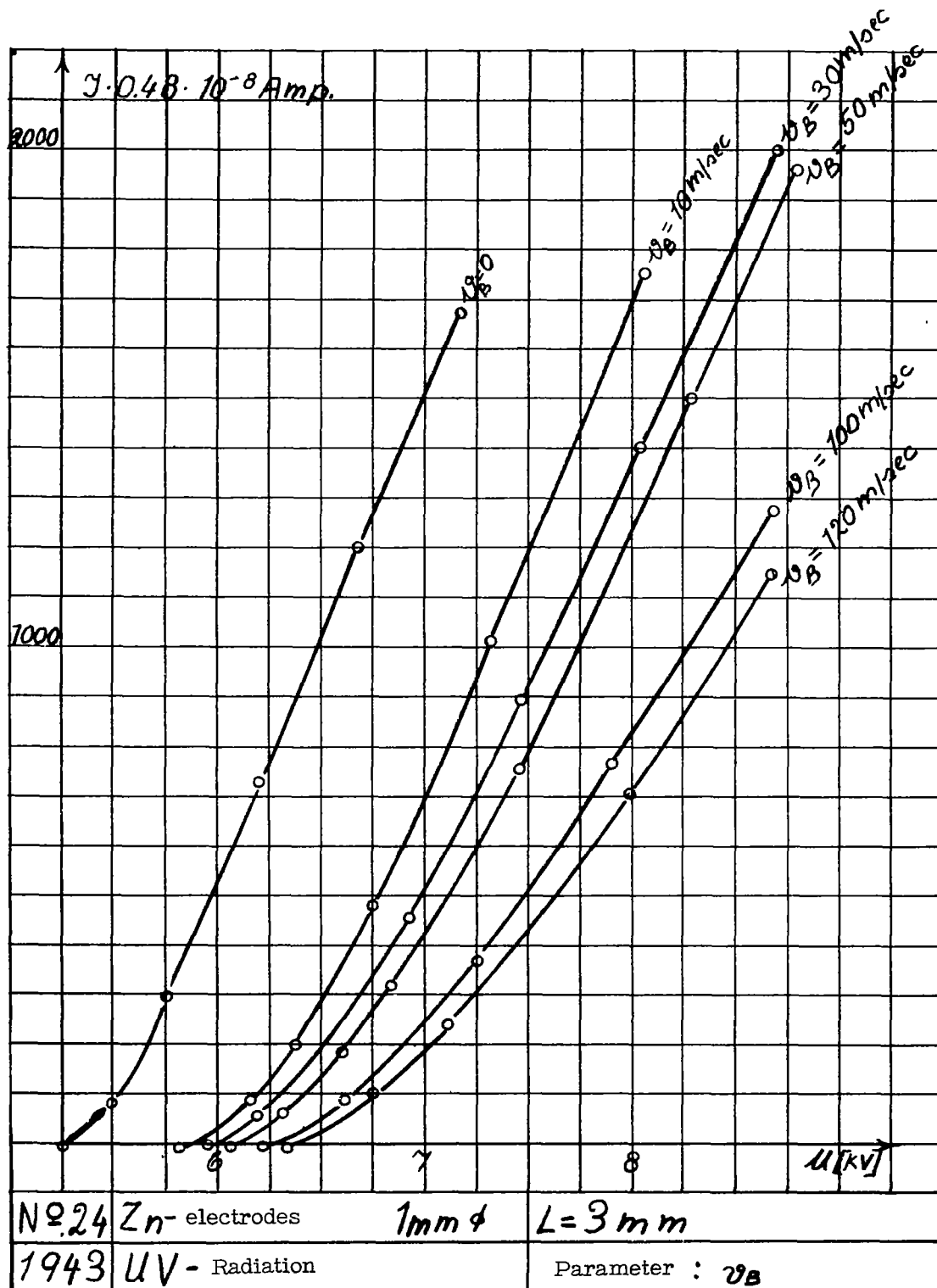


Figure 24.

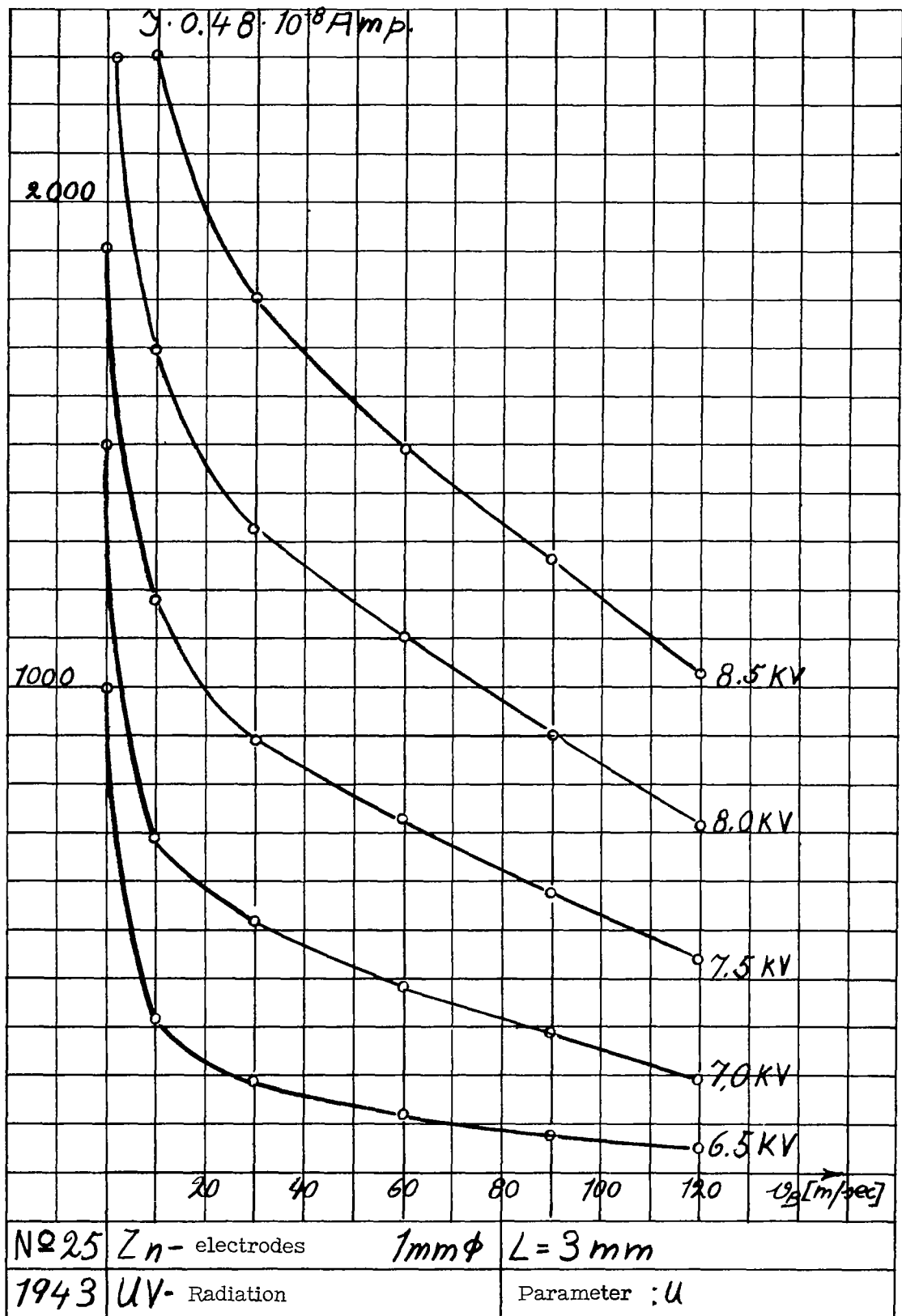


Figure 25.

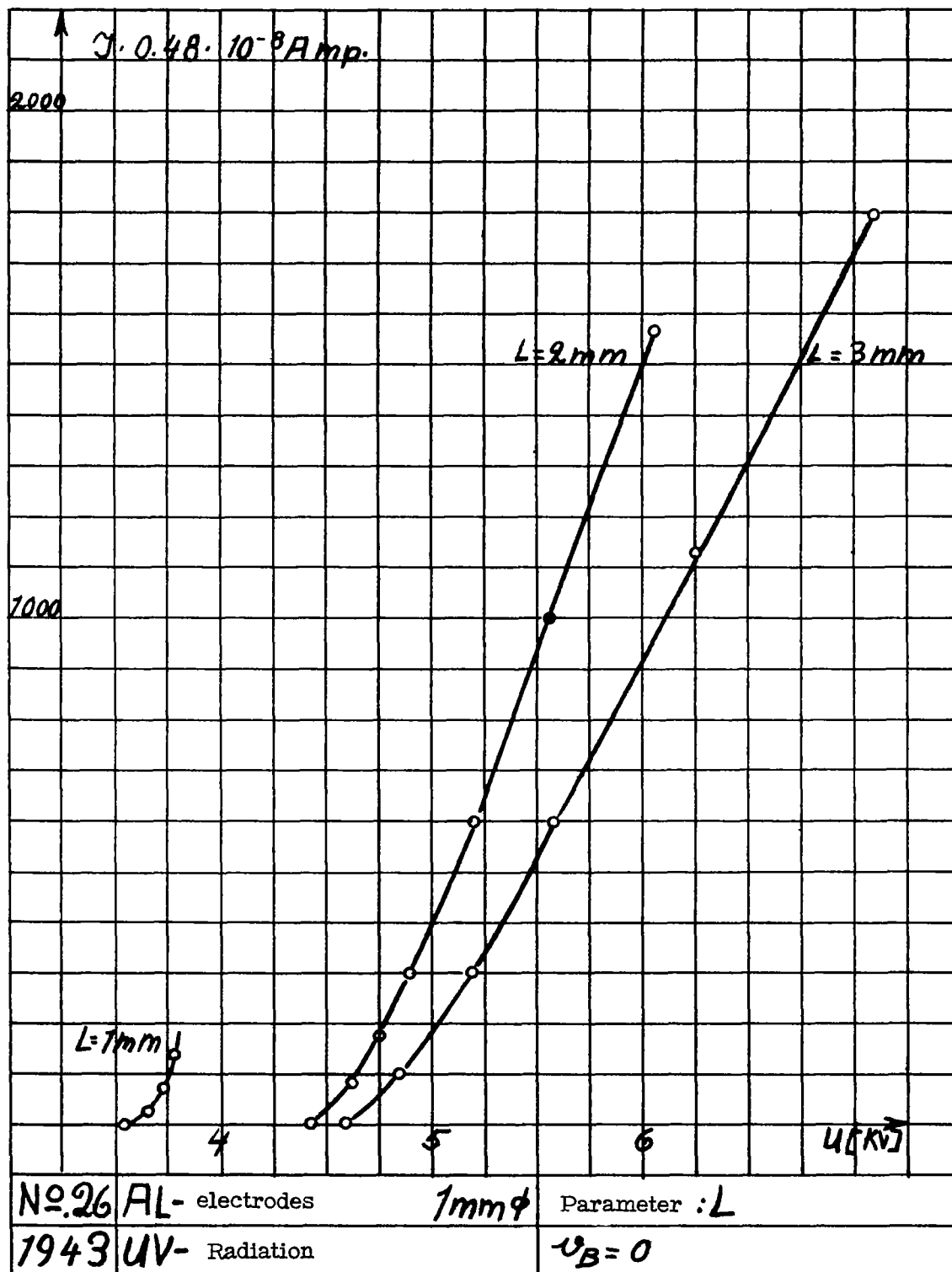


Figure 26.

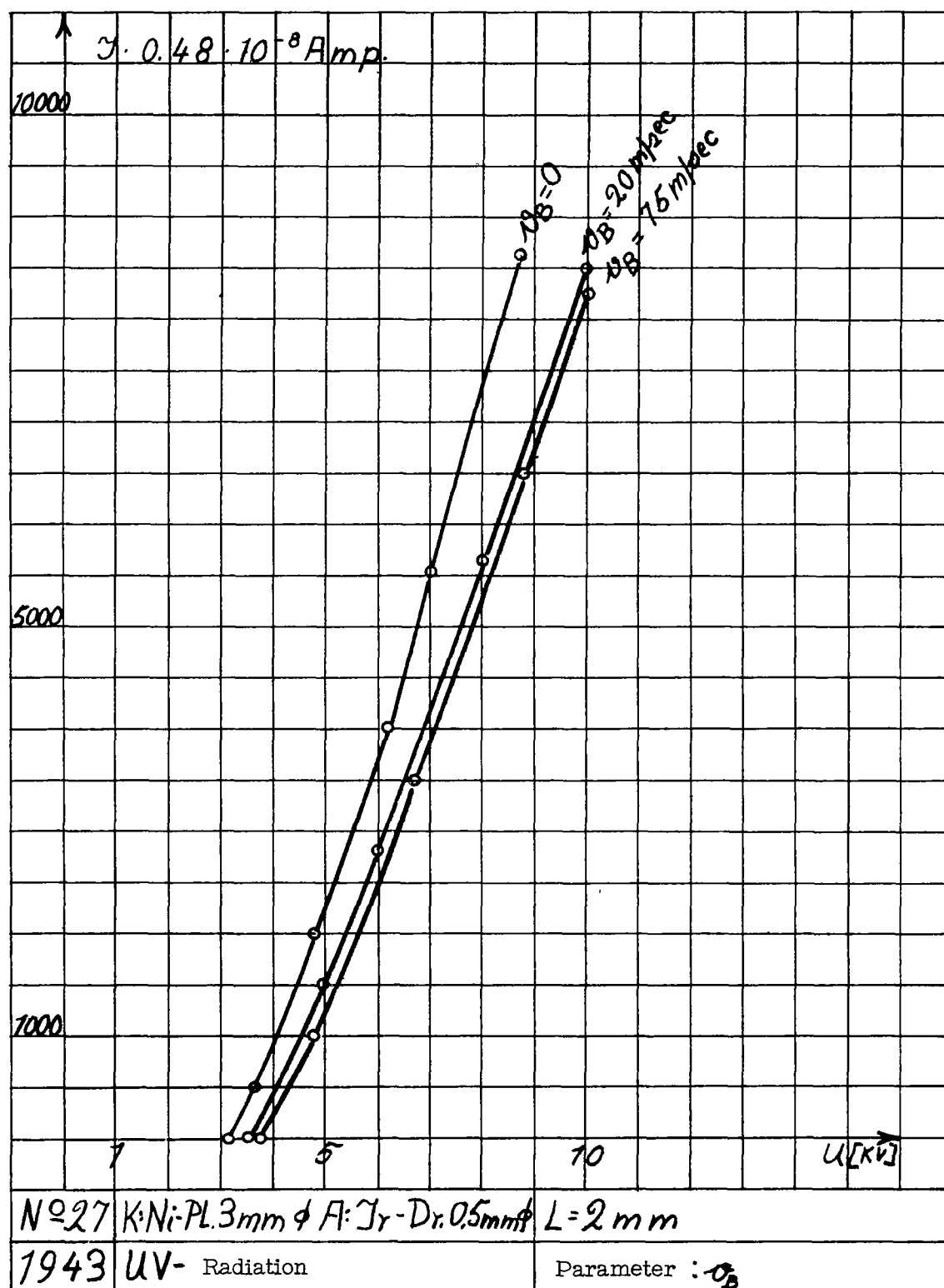


Figure 27.

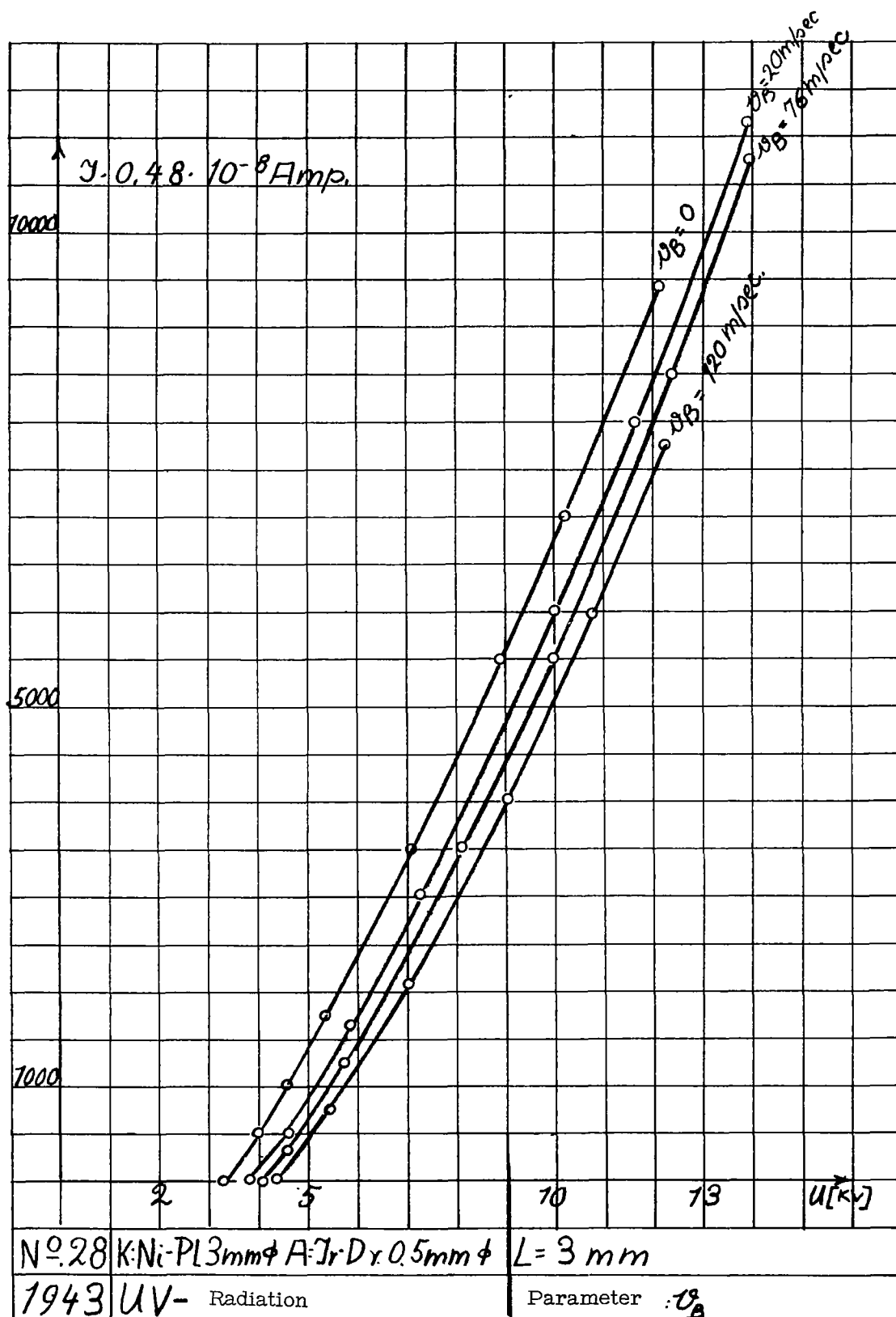


Figure 28.

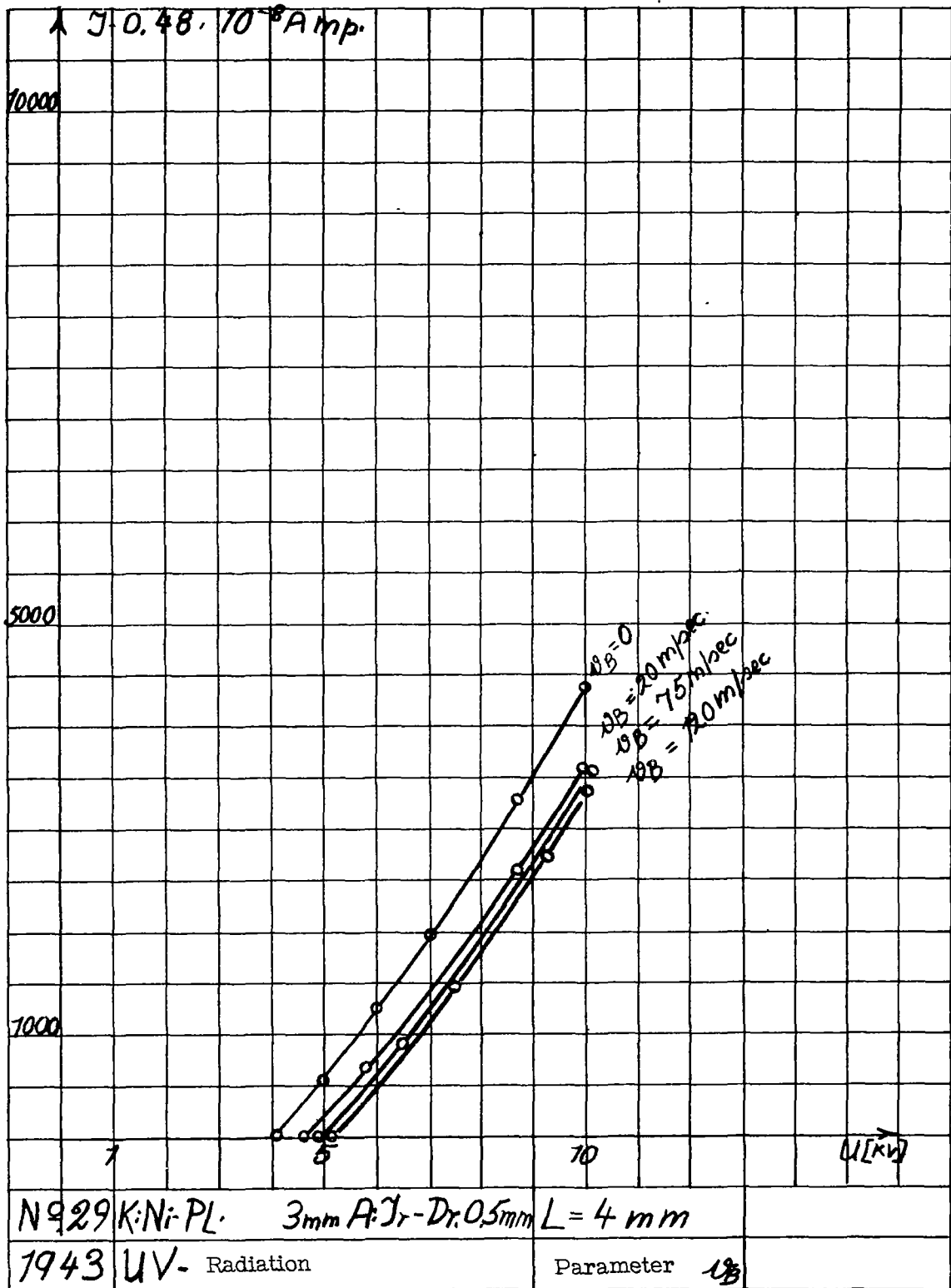


Figure 29.

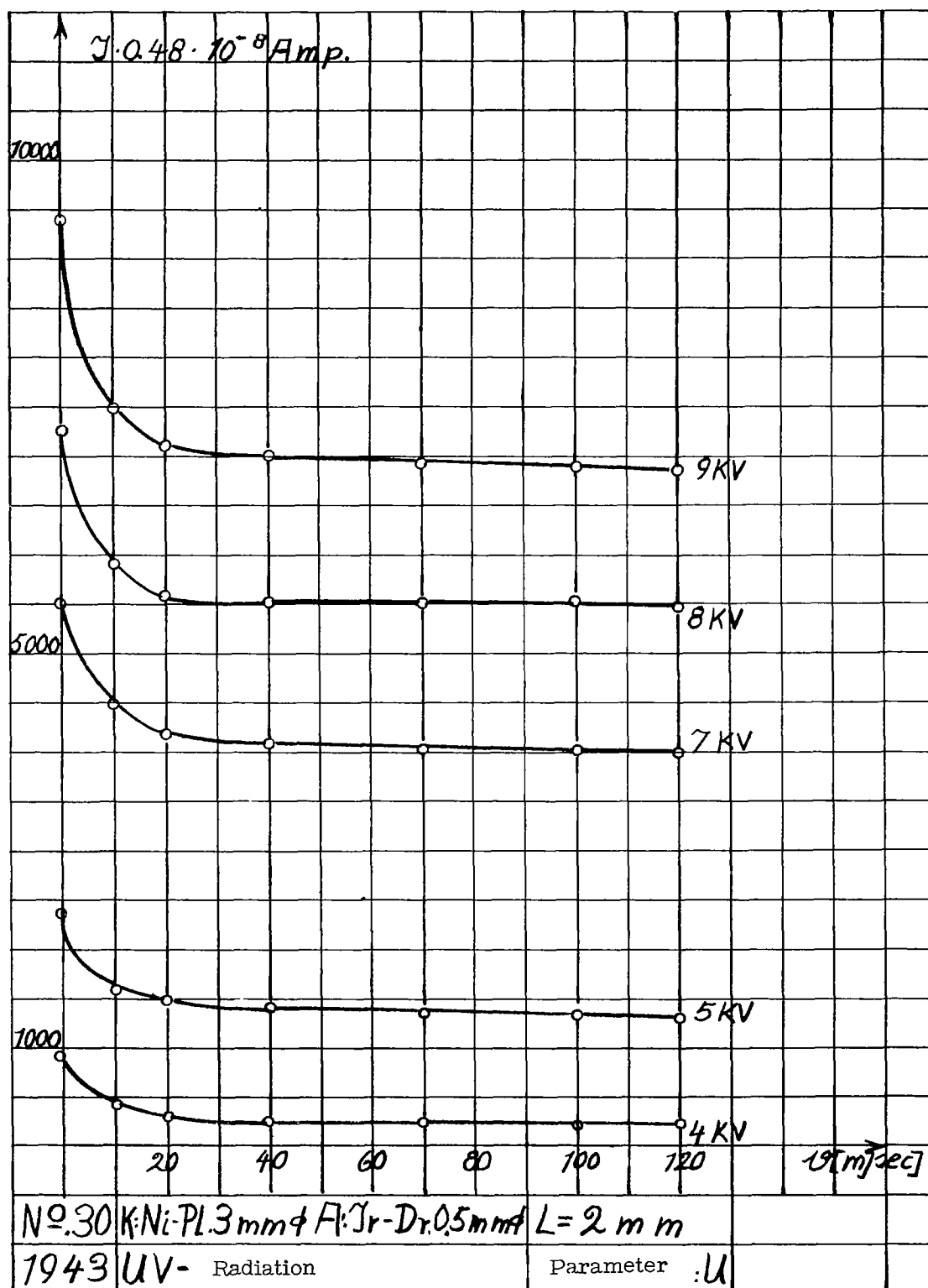


Figure 30.

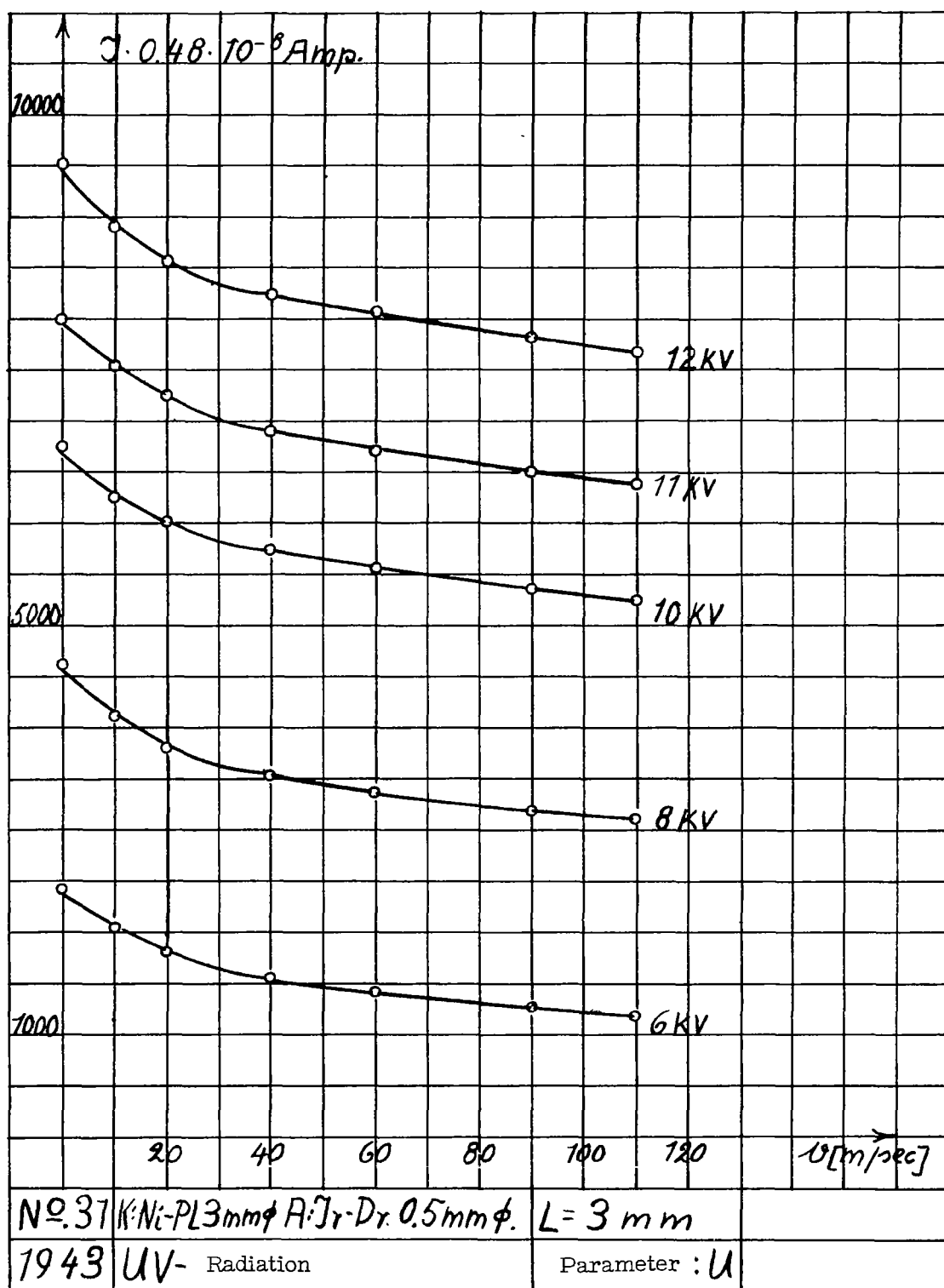


Figure 31.

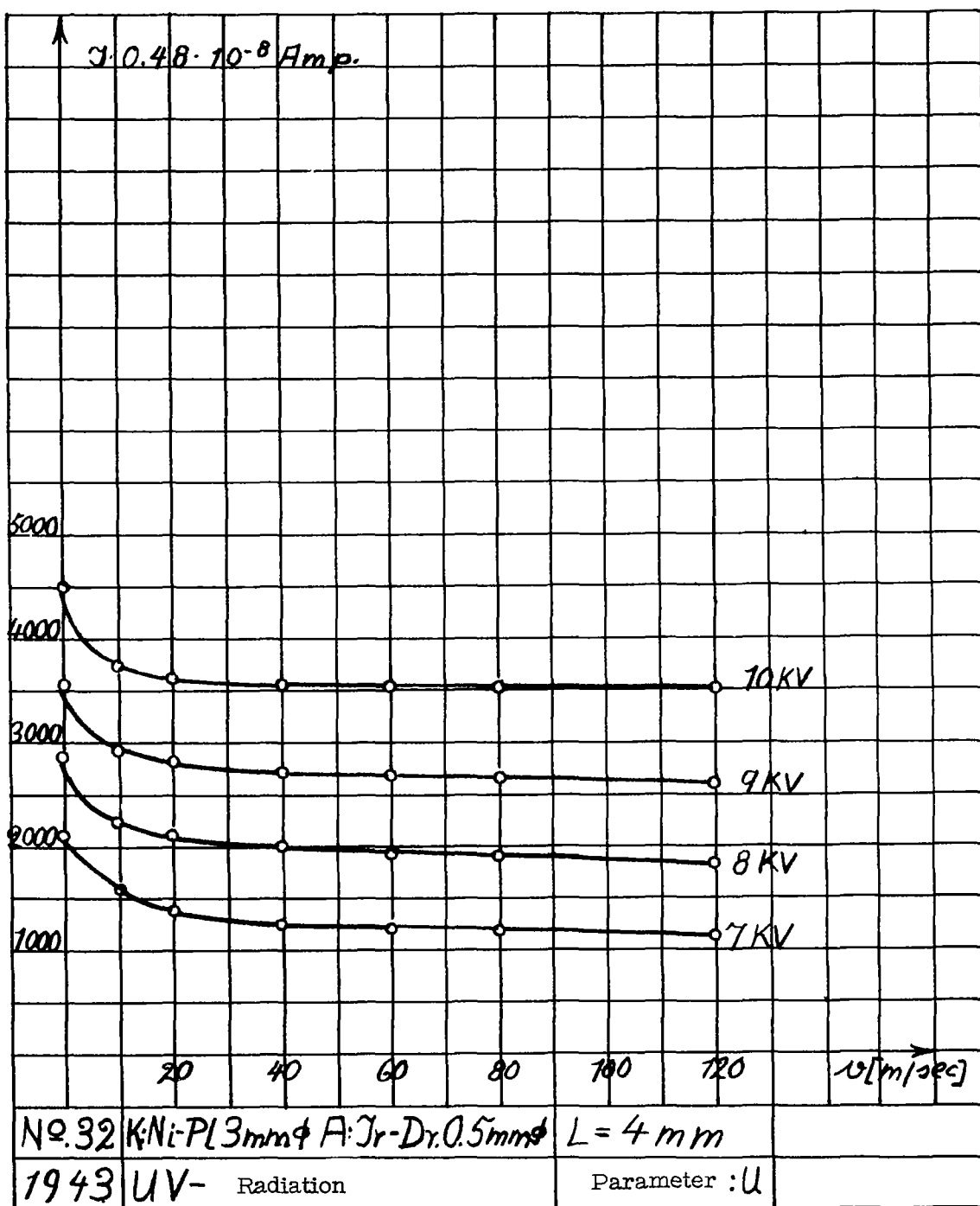


Figure 32.

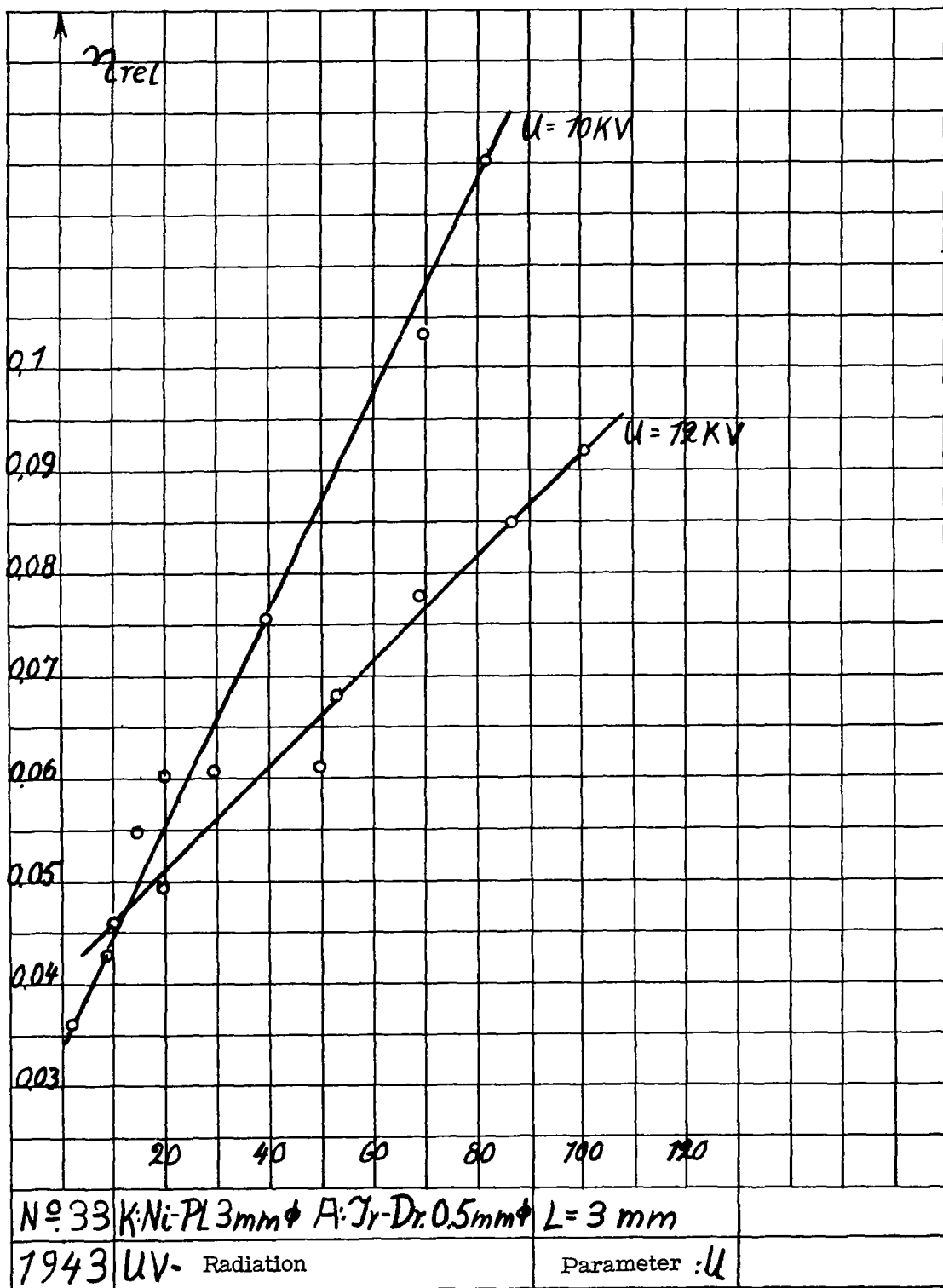


Figure 33.

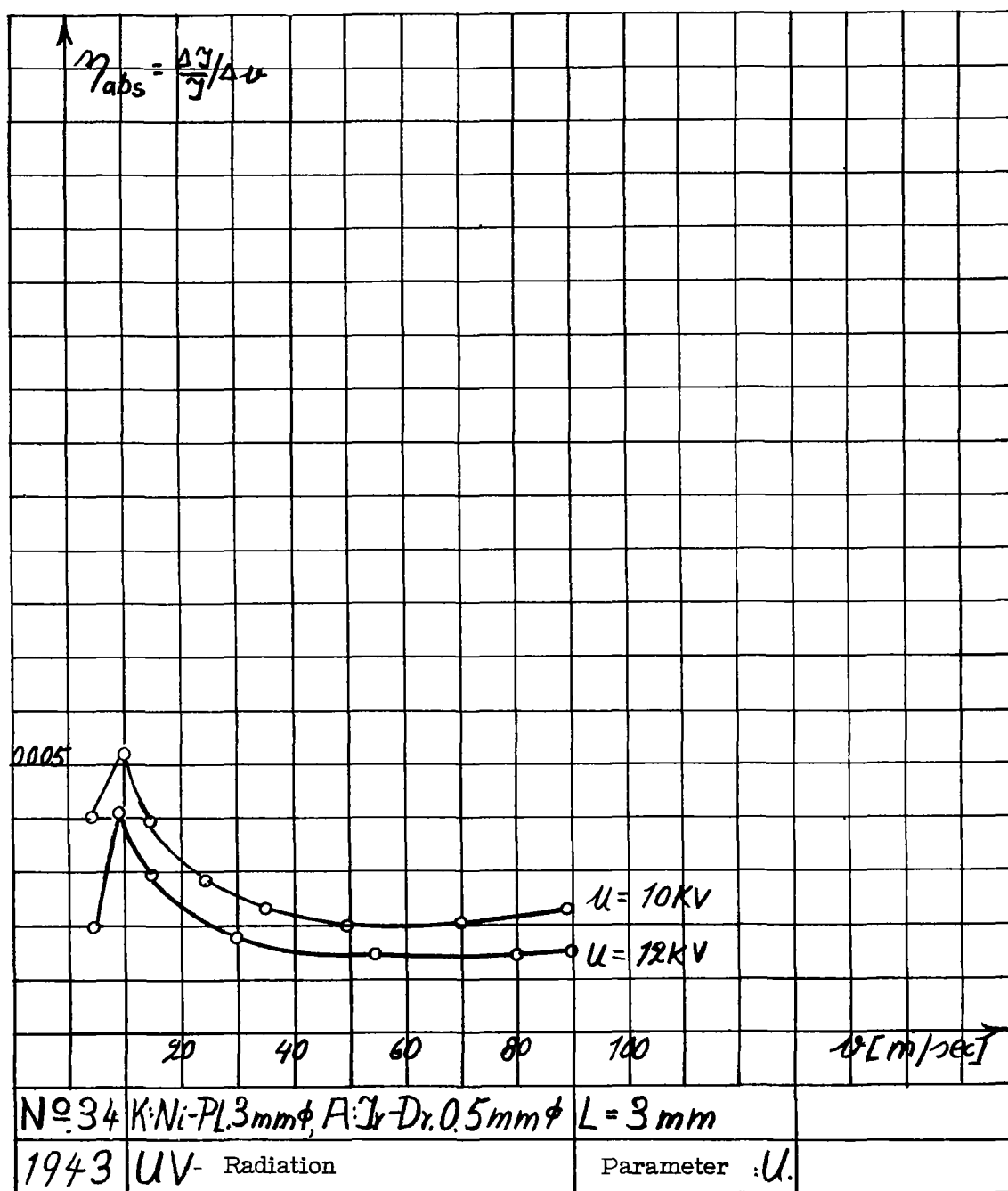


Figure 34.

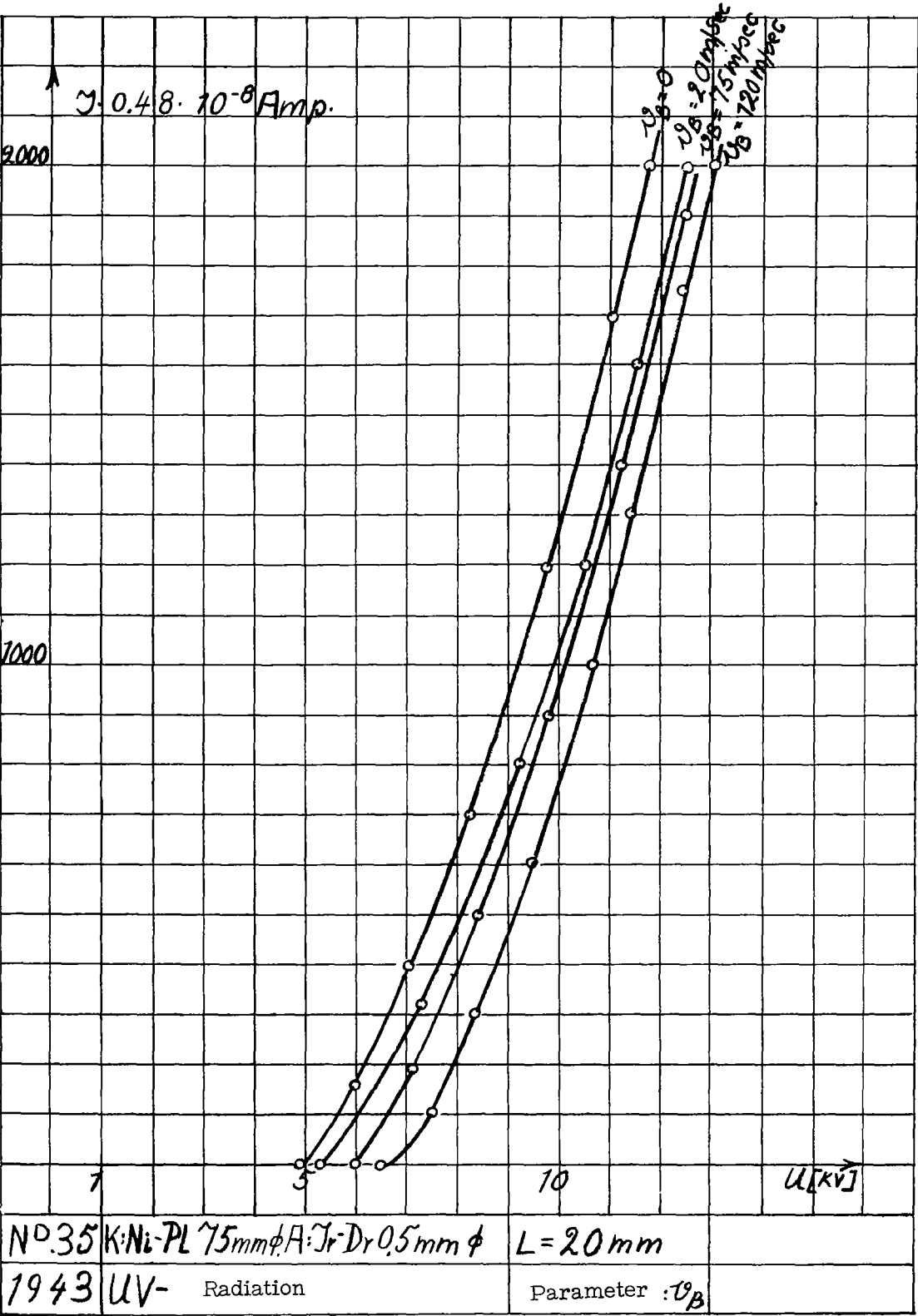


Figure 35.

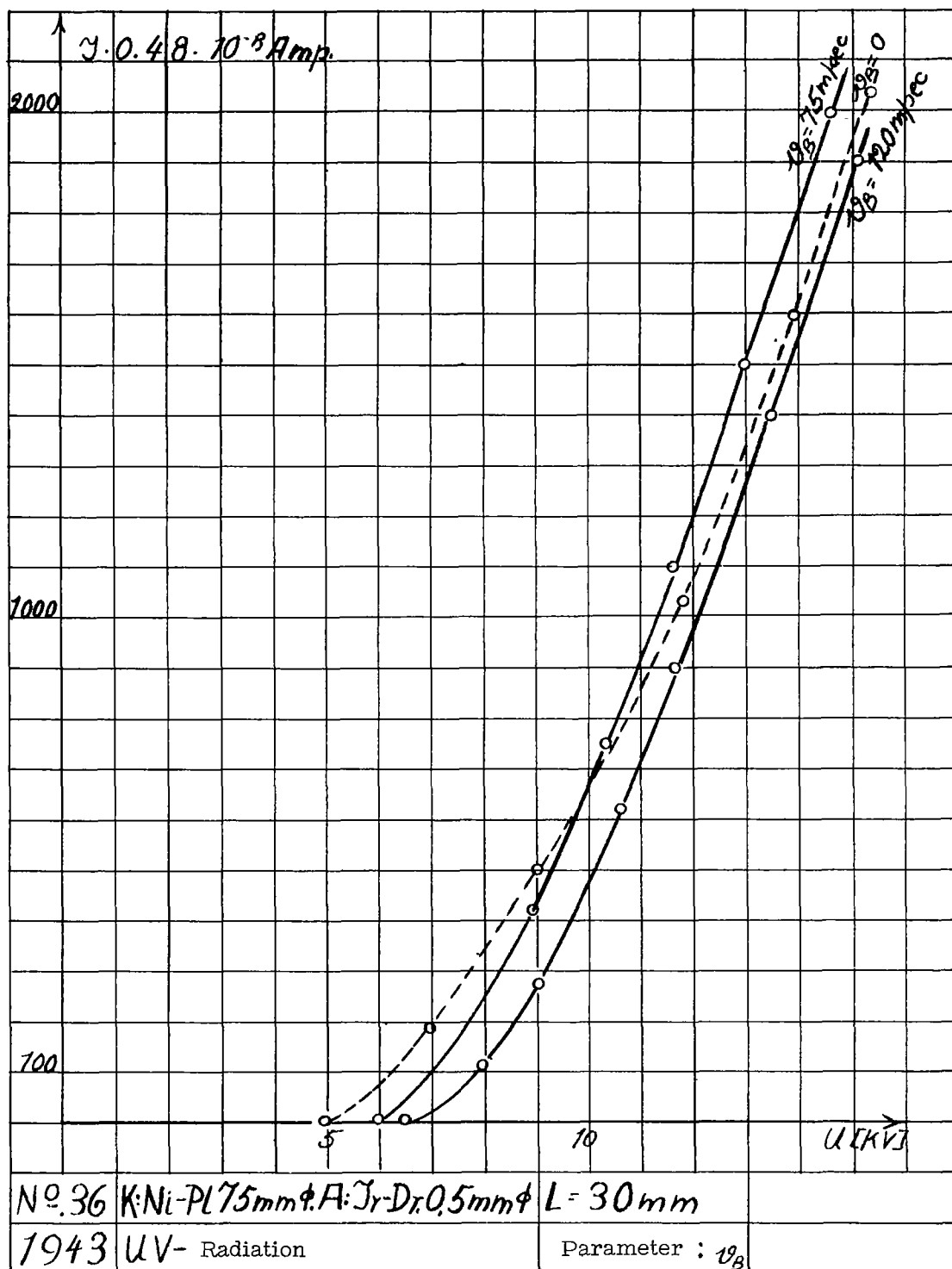


Figure 36.

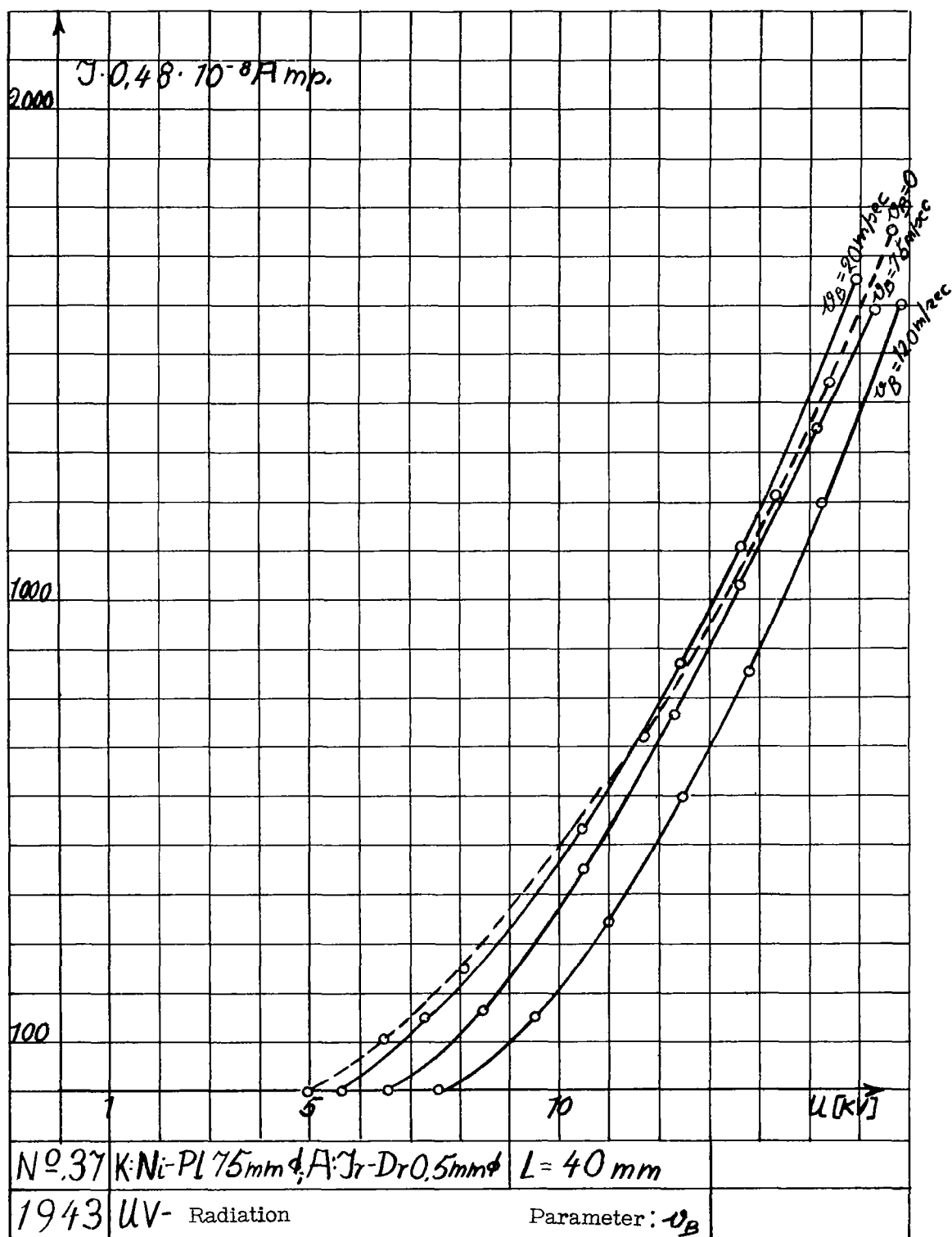


Figure 37.

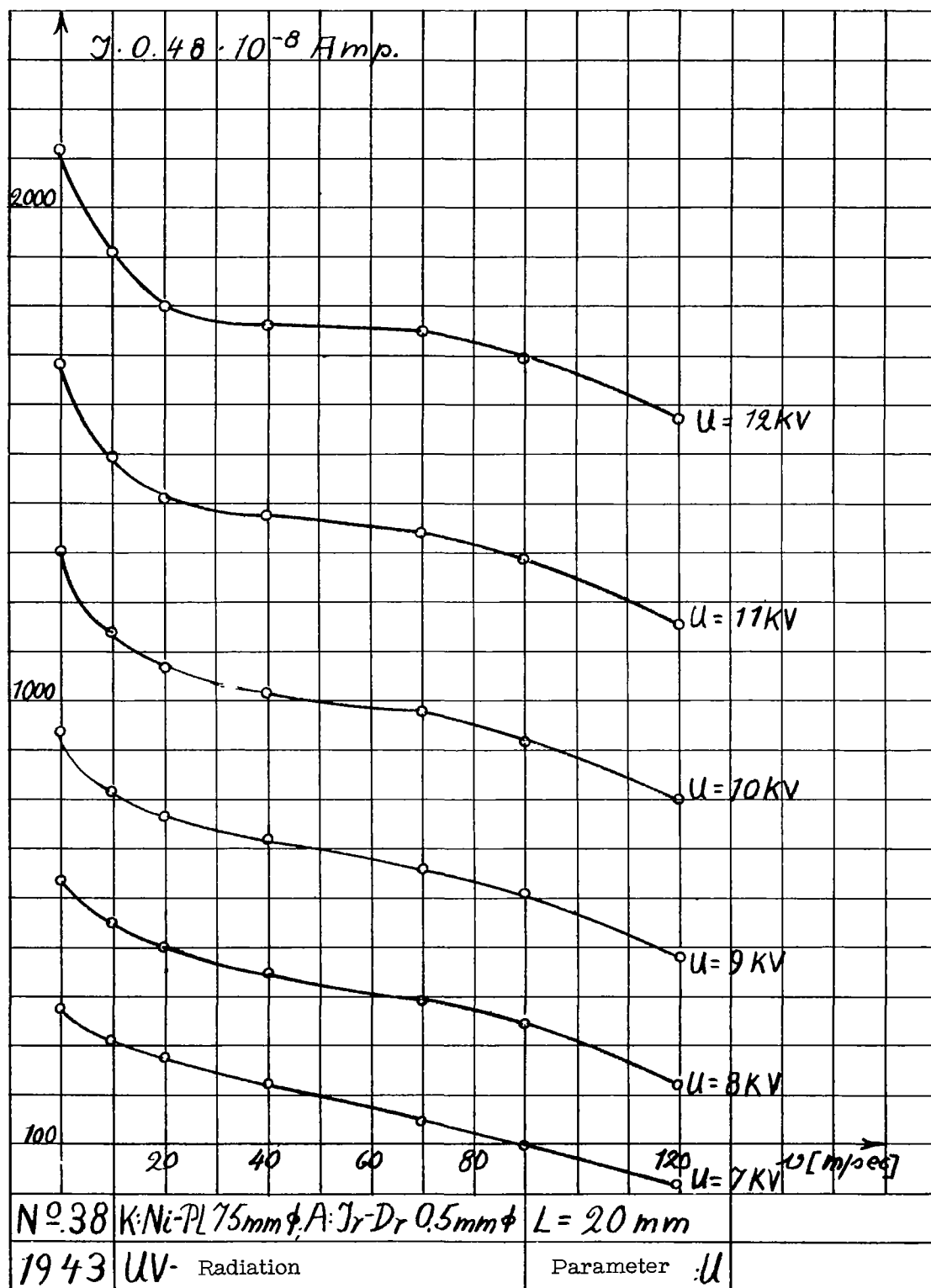


Figure 38.

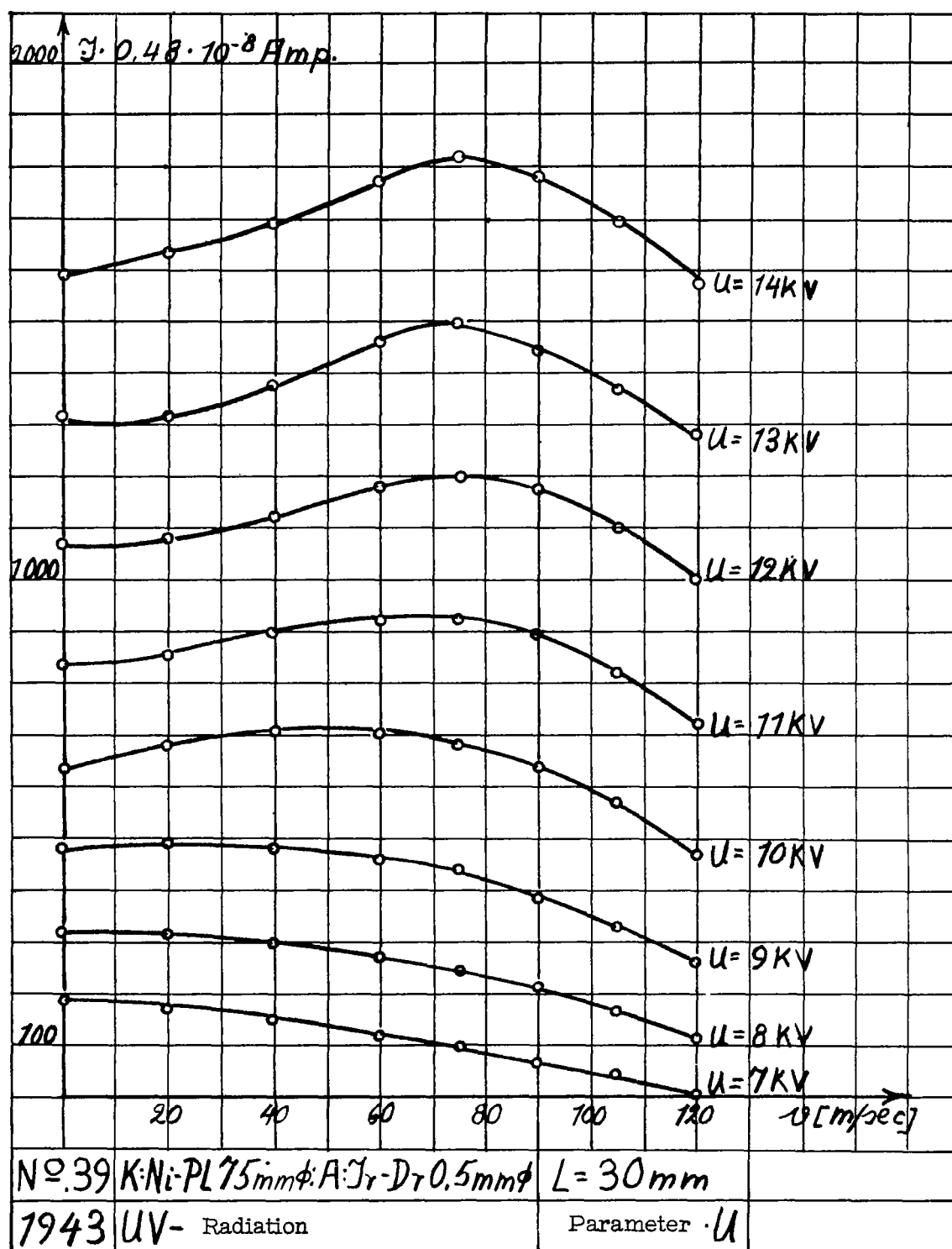


Figure 39.

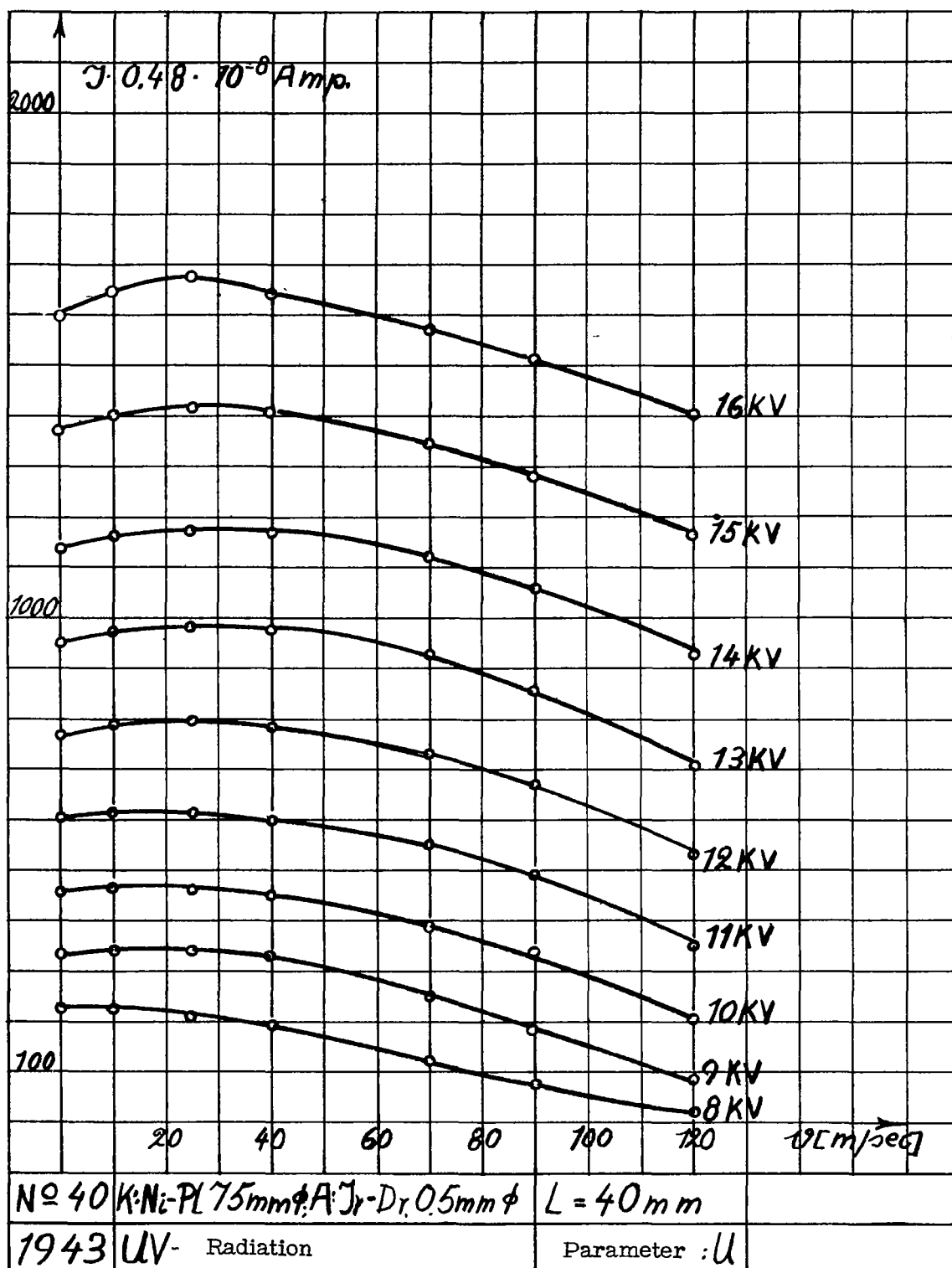


Figure 40.

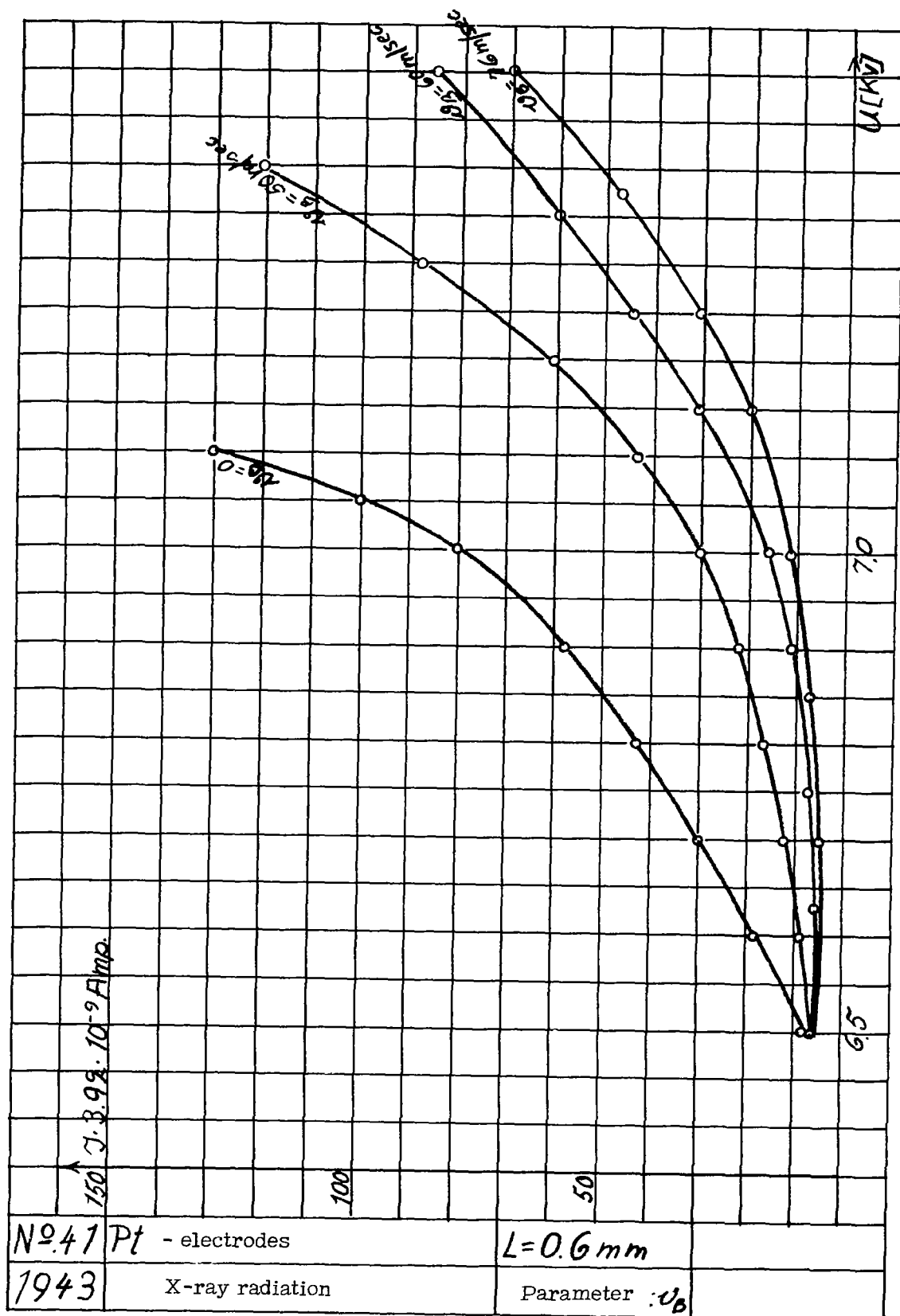


Figure 41.

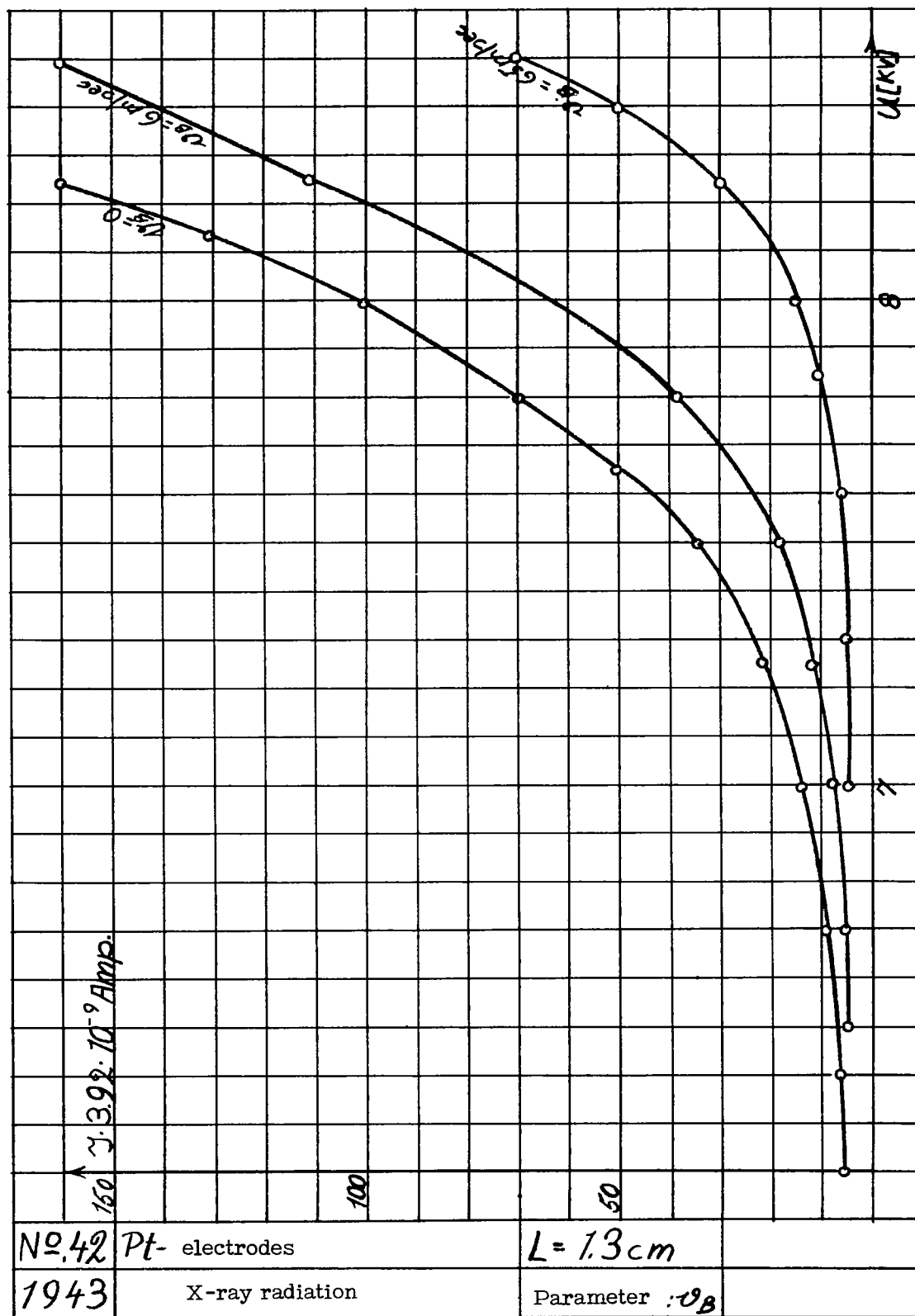


Figure 42.

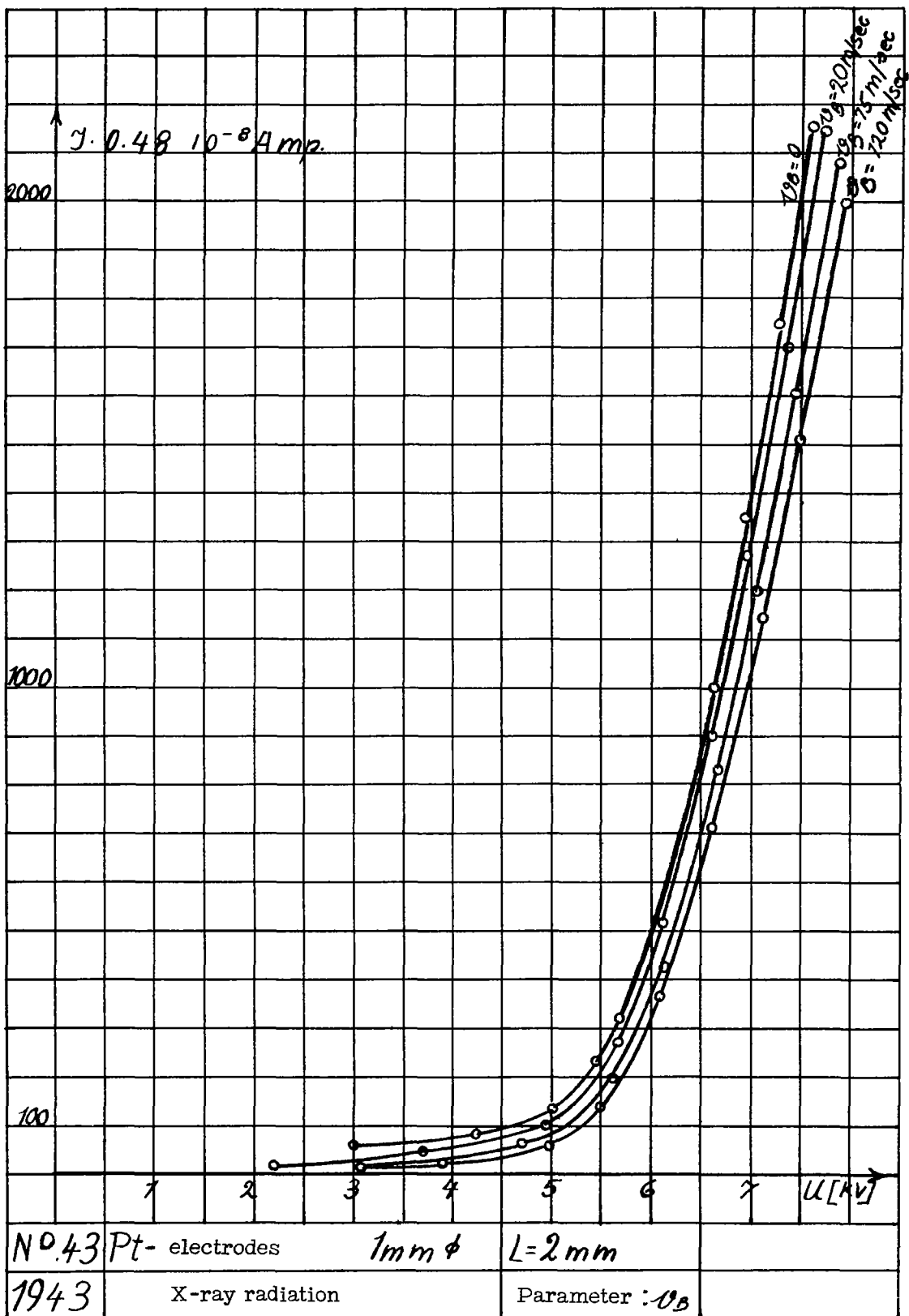


Figure 43.

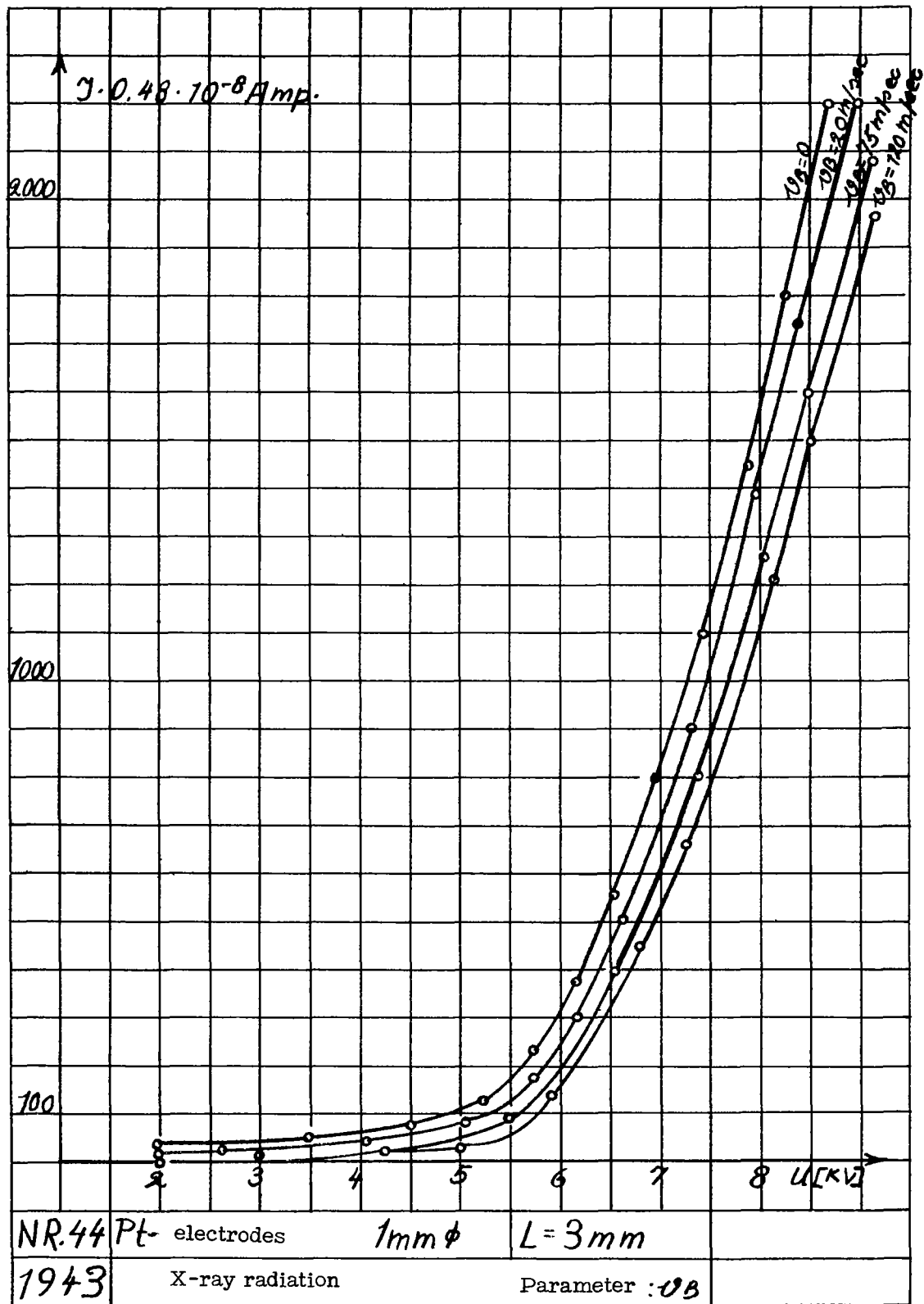


Figure 44.

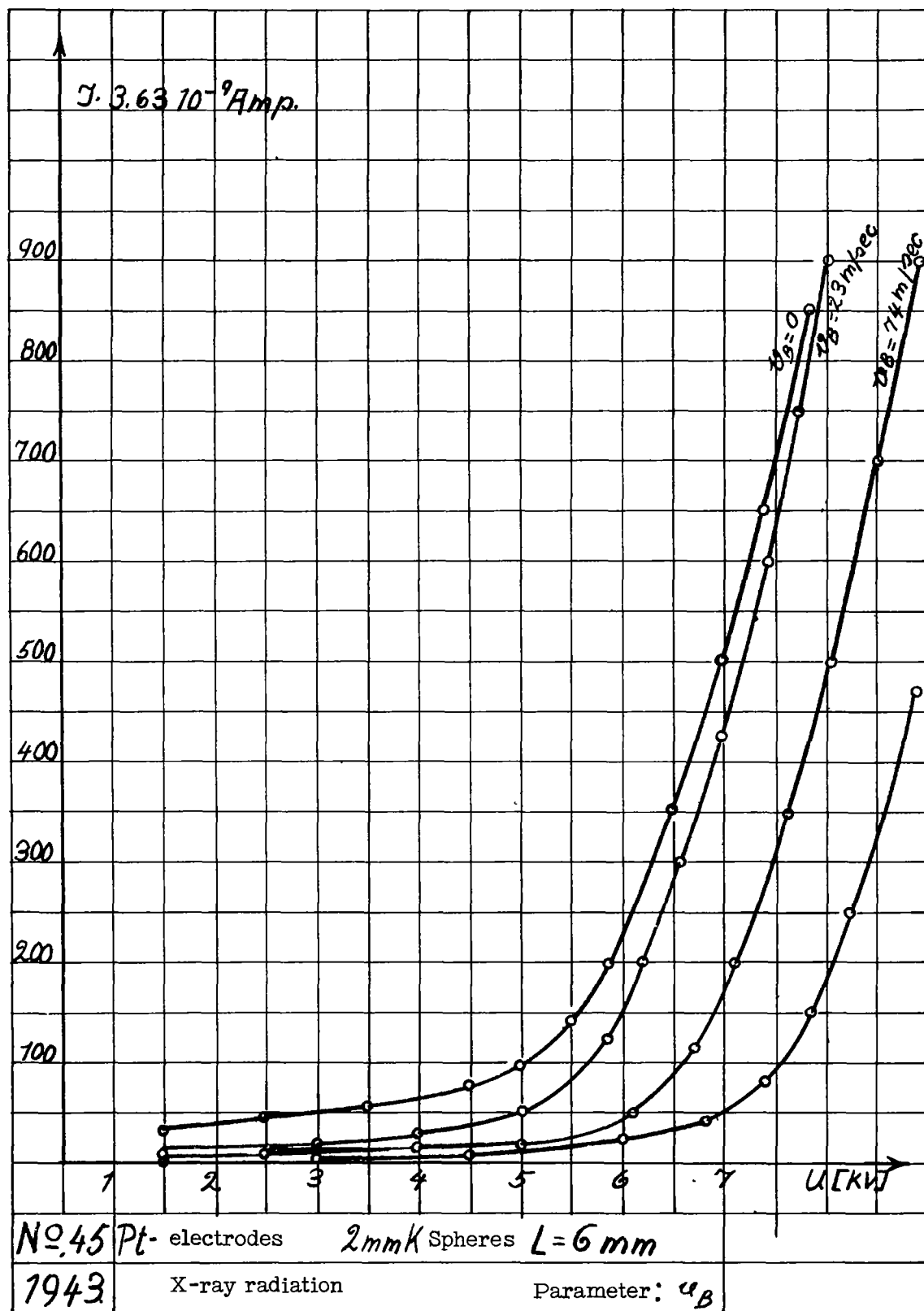


Figure 45.

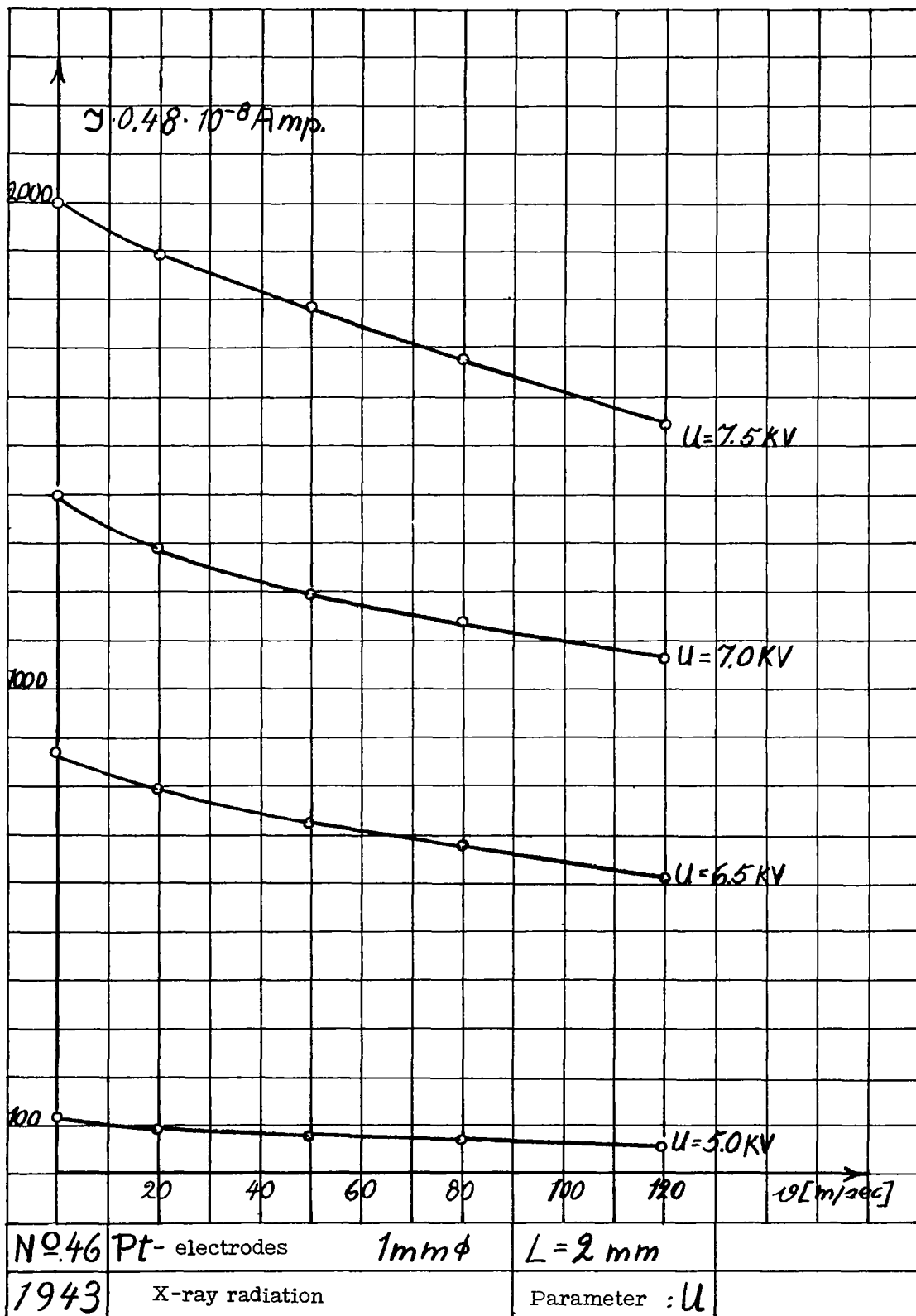


Figure 46.

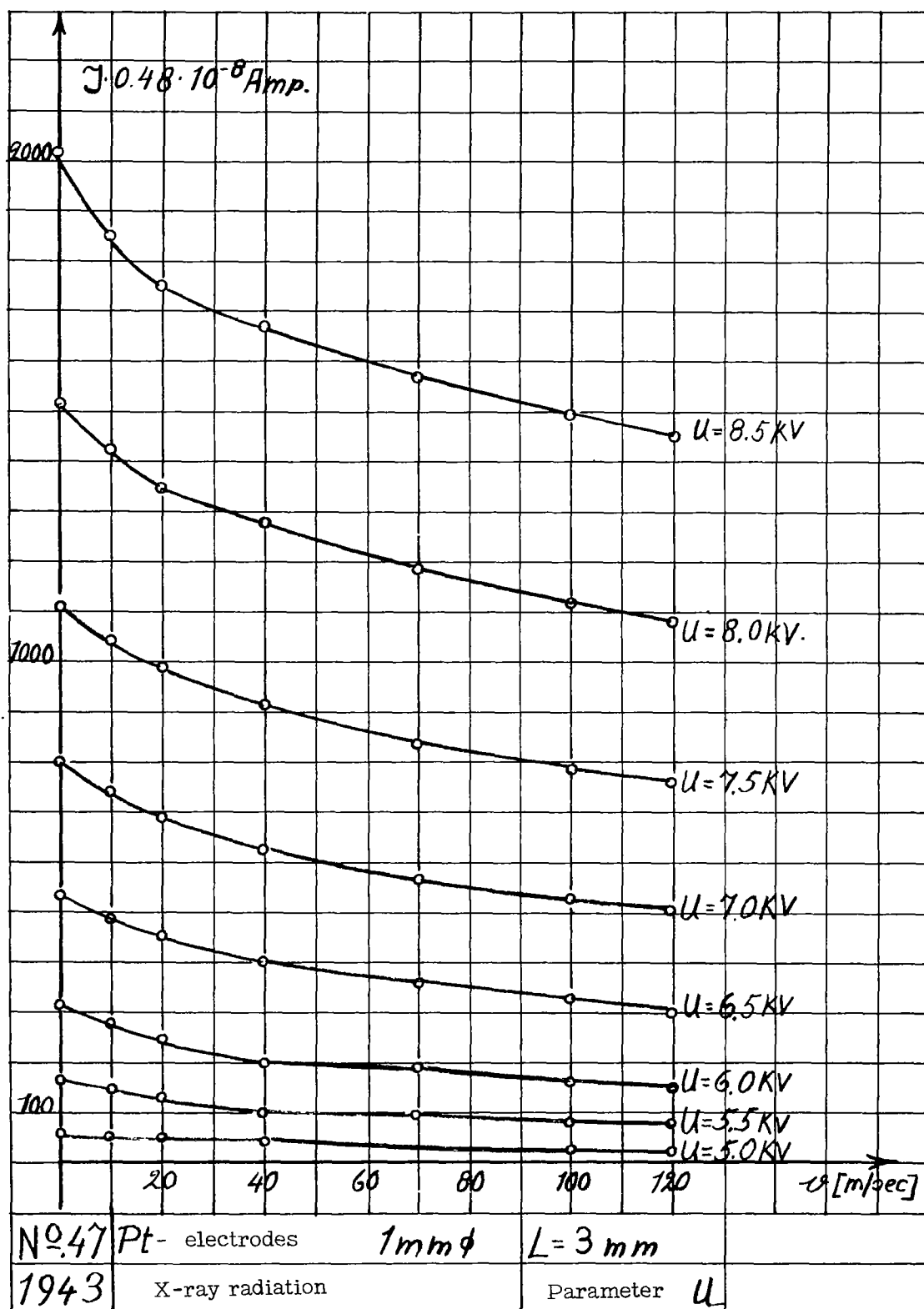


Figure 47.

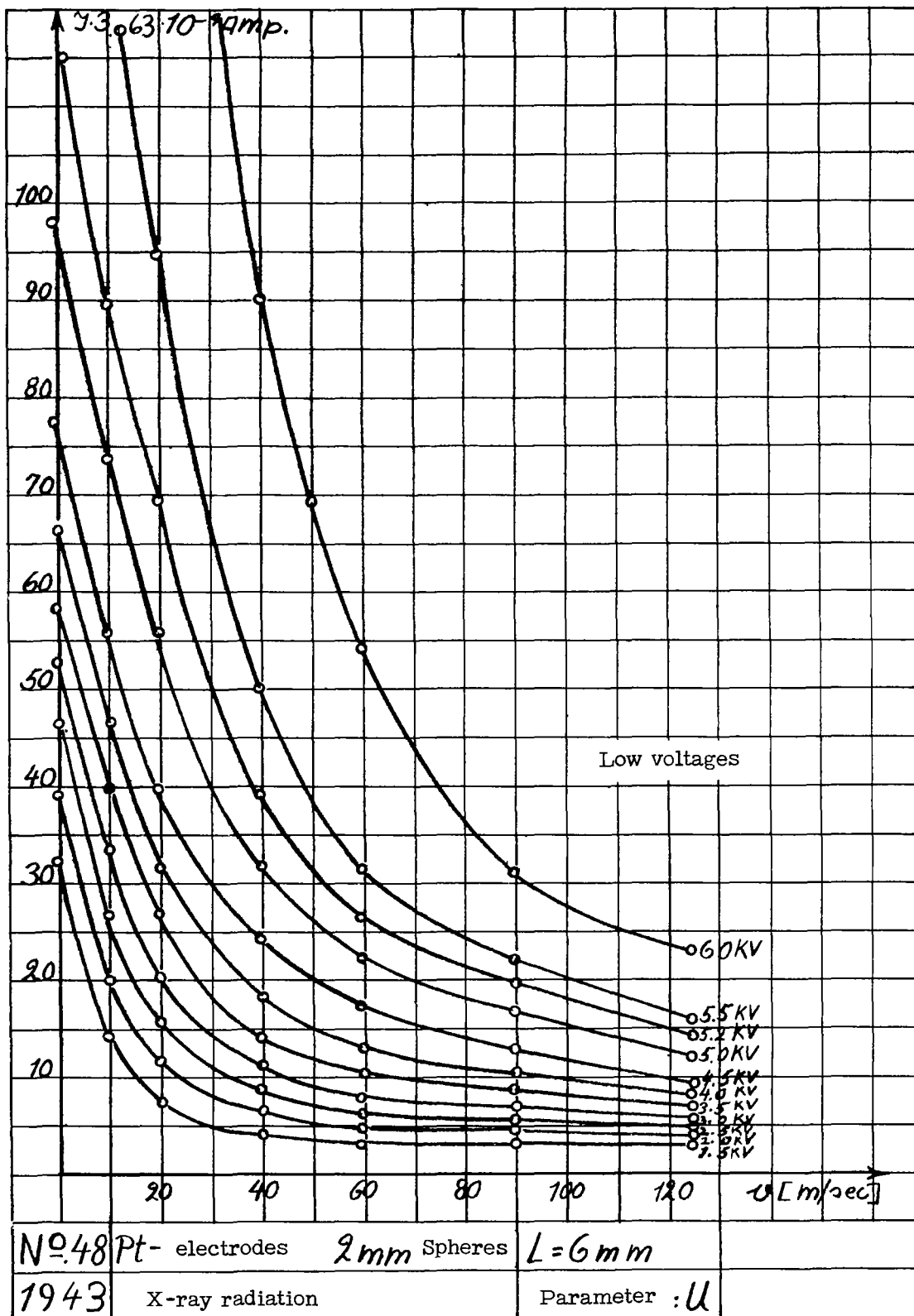


Figure 48.

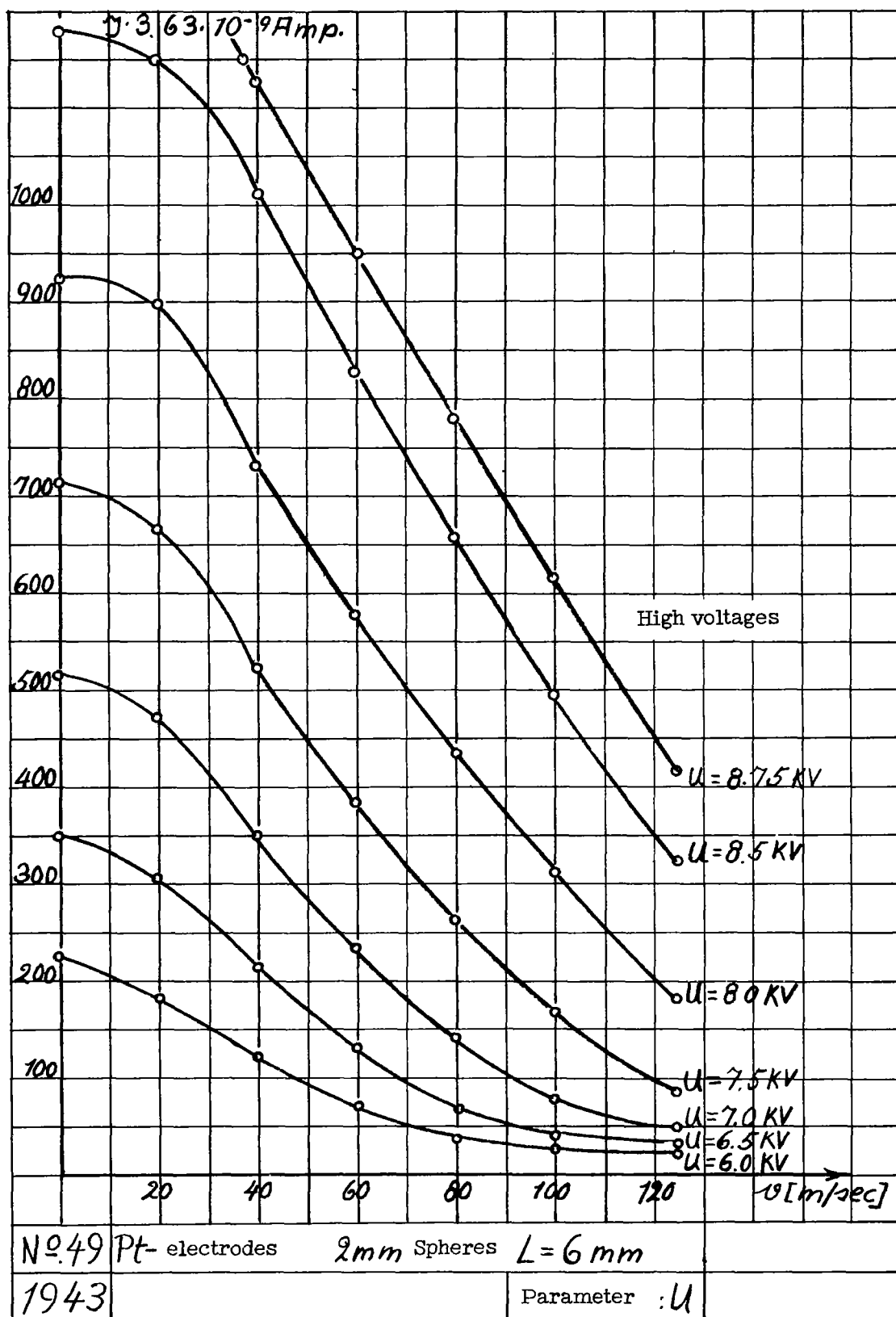


Figure 49.

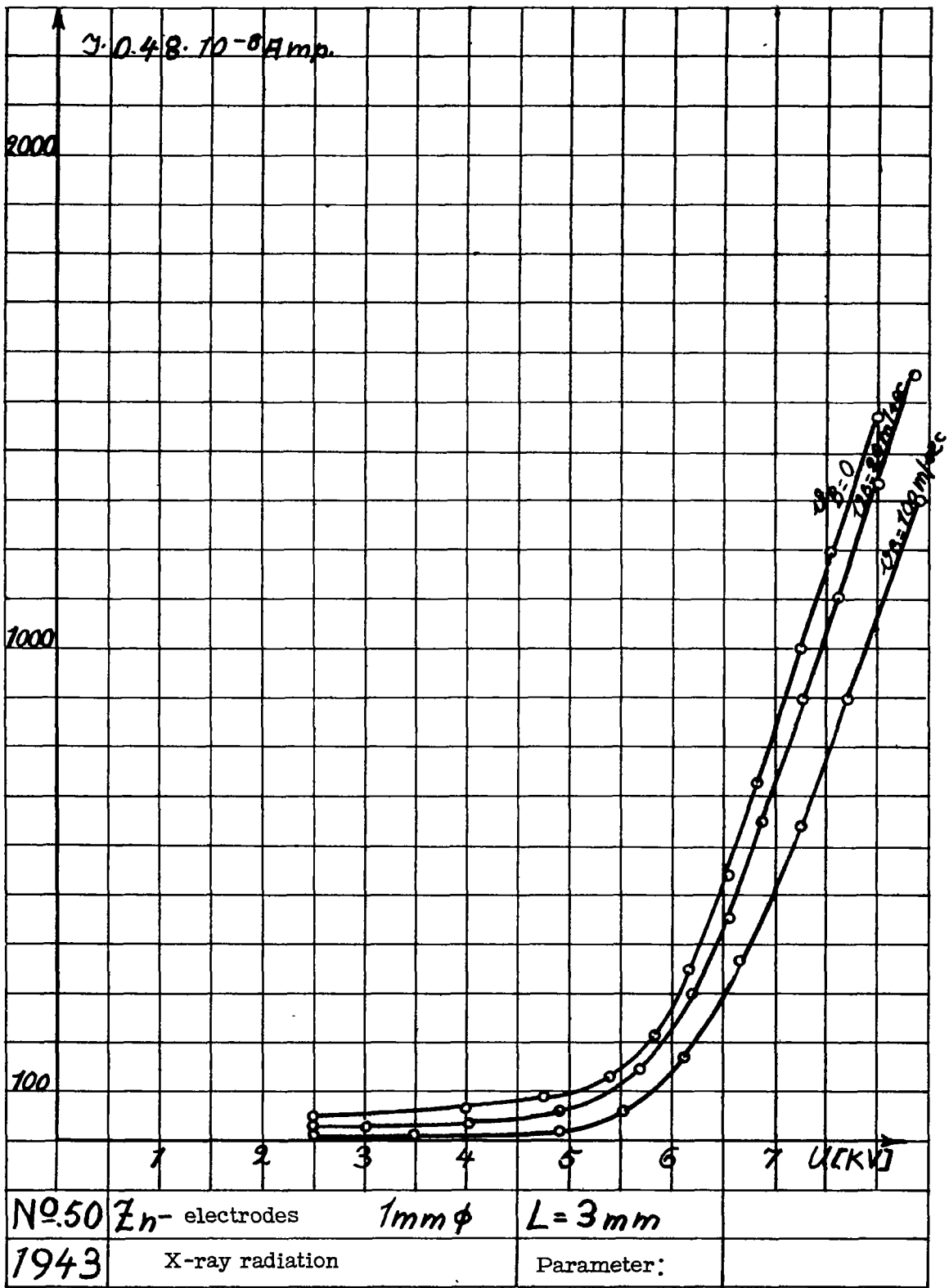


Figure 50.

NASA Technical Library



3 1176 01441 5666